Industrial QUALITY CONTROL

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Some Applications of Quality Control Techniques to Clerical Work

What ASQC Has Done for Quality Control

The Technique of Regression Analysis

Statistical Control in Continuous Chemical Processing

Some Applications of Quality Control Techniques in Motor Oil Can Filling

Planning and Operating a Receiving Inspection Department

QUALITY through Scientific Methods

Journal of the
AMERICAN SOCIETY FOR QUALITY CONTROL

Industrial Quality Control

Vol. XII **AUGUST, 1955** **No. 2**

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IT PAYS (II) . . .

In the June issue editorial we discussed the subject of advertising and its effect on each of us as part of the general consuming public. In the two months that have passed since then you have had a chance to look at quite a few magazines. Did you follow our suggestion and check some of the advertising? Didn't you learn something new and valuable that you wouldn't otherwise have picked up?

Let us now take a look at another side of the picture—the effect of advertising on each of us as employes of the companies we work for.

In the first place, each of us receiving this copy of IQC also receives one or more other trade or business publications whose editorial content is designed to keep us abreast of the latest developments in our particular fields of interest. It is almost axiomatic that better performance of our jobs and hence better service to our employers is achieved through this method of "self" education.

Everyone recognizes that his professional development and service to his company is greatly improved by the technical information gleaned from the business magazines he reads. But did you ever stop to think that each of us owes to our employers more than just technical excellence. There is much more to most of our jobs than the computation of a suitable sampling plan, the calculation of control limits for operation 14 on part No. XYZ.

To some extent this broadness depends directly on the quality control program in each particular company. Much has been published in IQC on the place of statistical quality control in the industrial organization; much more will continue to be published. A good many companies have had demonstrated first-hand the real value of a quality control department which is set up as a service organization to assist all of the other departments, including management itself. Each day finds more and more companies discovering this real value of a quality control program, but far too many are still thinking in terms of the "quality control" of ten years ago. They have not yet expanded their QC programs either because of lack of knowledge as to how useful such a program can be to them. A certain conservative wariness and show-me attitude, which is perfectly good provided they are willing to be shown, or a bitter experience with an ineptly managed program which has forced them to relegate their QC program to the dark recesses if not get rid of it altogether. This latter condition is, of course, infrequent but nevertheless most deplorable for the particular company affected. It is one of ASQC's major aims to provide all members with sufficient, continually expanding knowledge to enable us to render the professional service to our companies that we should be rendering to eliminate this sort of thing completely.

Before returning to the main track again, let's pause long enough to observe that statistical quality control is a *decision* tool. When we speak of "quality" we are referring not just to the physical "quality" of the manufactured product, we refer specifically to controlling the "quality" of any decision we are called upon to make. A truly useful Quality Control Program therefore makes use of this concept and is so located in the company organization that the director of quality and his staff can assist in applying statistical quality control techniques to *any decision problem*, whether it be in inspection, production, manufacture, engineering, design, research, accounting, purchasing, administrative procedures or management.

With this concept as a goal toward which we can work so that all companies can enjoy the benefits of a real quality control program, is it readily apparent that we owe our employers quite a little more than mere technical excellence and proficiency in handling statistical quality control techniques? Can you see that this proficiency is only one of many that we should have?

This brings us back now to the role of advertising in business publications and in particular in IQC. A good many people regard all advertising as one of those necessary evils they call "commercialism." This is not too uncommon an attitude among the professional societies and has spread simply because of the few very poor ads that continue to appear. Industrial advertisers have made great progress in developing conscientious advertising programs; they are continuing to work on the problems—and there are many.

Actually, rather than to categorically condemn all advertising because of the few poor ones, we should regard the advertising content of our business publications as simply another area in which we should keep up to date in the same way that we keep up to date on technical advancements published in the editorial columns of the magazine.

(Continued on page 40)

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Department Store Uses of Statistical Quality Control*

CLAUDE S. BRINEGAR

The Emporium, San Francisco

The modern, large department store is deceptive. In appearance, its main activities seem to involve only the selling of merchandise to customers. In fact, however, for every employee assigned to the selling floor there are probably two employees engaged in nonselling activities. And for every piece of paper needed for a customer transaction, there may be five pieces needed to get the merchandise from the vendor to the selling floor. Such diverse activities mean, consequently, that the majority of statistical quality control opportunities are found not on the selling floor but behind the scenes.

These behind-the-scene applications are found in the accounting departments, in the operational division, and in different aspects of overall management. This article will discuss some interesting examples of such applications, drawing upon experiments carried out at The Emporium, San Francisco's largest department store.

APPLICATIONS IN ACCOUNTING

A good illustration of an accounting application is found in Accounts Payable, the department that pays the bills owed *by* the store. At The Emporium we suspected that completely double-checking the invoice extensions made by three experienced comptometer operators was unprofitable, although some control was desired. Analysis of 15,000 invoices demonstrated (1) that costly errors were concentrated in the invoices representing very large purchases and (2) only very few invoices actually contained errors. This situation clearly suggested the possibility of a sampling plan of the acceptance/rectification type. We inaugurated such a plan, treating each operator's output of about 1,000 invoices under $500 in value as an inspection lot (the larger-valued invoices continued to be double checked.) The inspection lots, which constituted about 80 percent of the total, were sampled when accumulated, usually once a day, according to a previously designated Dodge-Romig double-sampling AOQL plan. If the sample was acceptable, the entire inspection lot was accepted as containing correctly extended invoices. If the sample was rejected, the operator was notified and the entire inspection lot was re-extended. Since the operators were capable of producing work well within the AOQL used, and usually did, the principal causes of errors were carelessness, fatigue, or illness. Significantly, Mondays and Fridays were the days most likely to see rejected lots.

This plan enabled us to eliminate nearly eight hours of checking-time daily, without materially increasing the number of undetected errors. Subsequent analysis by auditing teams indicated that less than 1/10 of one percent of the accepted invoices contained errors. In addition, since the operators soon materially improved their accuracy, we were able to lighten the inspection standards in a short time, producing additional savings in time and expense. New or inexperienced operators were sampled with the stricter plan until their abilities were established.

A similar application was found in Accounts Receivable, the department handling bills owed *to* the store. The charge account slips are filed in large, alphabetically-arranged drawers, with each drawer containing the file cards of about one thousand accounts. The drawers are assigned to individual clerks, who are then each responsible for correctly filing about 20,000 of the charge-slips monthly. Since misfiled slips usually result in billing one customer for items not purchased, and submitting a corrected bill to the other customer, such errors produce adverse customer reaction, and, of course, should be minimized.

The established procedure for detecting the misfiled slips required each of the twenty clerks to devote about one hour daily to checking the files of one of the other clerks. The checking was such a repetitious procedure, however, that even after 100 percent verification, we still received about 50 customer complaints monthly that were directly traceable to misfiled slips.

We started keeping detailed records of all misfiled slips located by the checking, and within two months found that three of the twenty clerks were responsible for nearly 90 percent of all errors. Under close supervision these three clerks soon became as efficient as the others, for they had apparently simply become careless. We instituted a sampling plan similar to the acceptance/rectification plan described previously—using one drawer as an inspection lot—and within a few weeks practically no errors were being detected. At the present time only the filing of new clerks is double checked, with the work of the regular clerks sampled at infrequent intervals. This application enabled us to nearly eliminate the checking, while, at the same time, the number of customer complaints traceable to misfiled tags remained essentially unchanged.

Similar illustrations exist in other accounting departments, such as Sales Audit, Internal Audit, and Payroll. However, since these examples are analogous to the two just described, we shall turn to some interesting applications found on the operating side of the department store, describing experiments both at The Emporium and elsewhere. Although some of these examples illustrate sample surveys instead of strict statistical quality control, they are included here both because of their general interest and because they have served to acquaint department store executives with the advantages of statistical methods.

*The author wishes to acknowledge his gratitude to the executives of The Emporium for their cooperation, advice, and assistance. Messrs. Howard Carver and Walter Kaplan deserve particular mention. Miss Betty Legarra of the Research Department assisted materially in carrying out the actual experiments. The author is currently employed by the Union Oil Company of California.

OTHER APPLICATIONS

An interesting application was reported recently by a large eastern store. Their wrapping and packing department was experiencing an unusual number of complaints due to damaged goods or improperly filled orders. Since the orders could not be checked completely without undue expense, the store decided to install a sequential sampling scheme to control the quality of the wrapping and packing work. Samples were drawn at random time intervals, and when low quality work was detected, subsequent packages were completely checked until a specified number were found to be correctly processed. The plan proved to be quite successful, with the employees becoming quality conscious and customer complaints quickly dropping to reasonable levels.

The J. L. Hudson Company, Detroit's largest, and the nation's second largest department store, has applied sampling techniques to study the activities of their supervisory personnel. By analyzing the actions of their 150 floor managers at random intervals during the day—they call it "work sampling"—the management was able to fit together an accurate picture, at a small cost, of just how the floor managers spent their working hours. An interesting finding—and one that all customers must suspect occasionally of all stores—was that their managers had so much supervisory and detail work that they were forced to neglect their primary responsibility of attending to customer's needs. Consequently, in addition to substantially increasing their staff of floor managers, the store also divided the job into different responsibilities, thus providing much-improved service to their customers. The "work sampling" studies are being extended to appraise other important supervisory jobs.

We have used sampling for similar purposes at The Emporium. For example, by analyzing the sales pattern of randomly selected departments, we were able to determine, from a ten percent sample, just how the sales were distributed throughout the day. This information enabled us to evaluate the expenses of night openings and other alternative operating schedules.

Statistical sampling has also been used to advantage in analyzing the competitive effects of branch store operations. By studying the shopping habits of a randomly selected sample of charge account customers, we were able to obtain an approximate measure of the extent to which The Emporium's new, nearby branch store was cutting into the sales of the main store.

INVENTORY APPLICATION

The examples discussed thus far were selected principally to illustrate the variety of department store operations that can be improved by the use of sample surveys and quality control techniques. The sampling plans and other details have been discussed only broadly, for we are interested mainly in the kinds of opportunities that exist. There is, however, one application that deserves consideration in greater detail. This application, which involves the use of quality control in taking the merchandise inventory, is of general interest not only because the inventory is an essential but costly part of operating a department store, but also because the technique we have employed has potential uses in many other businesses where merchandise inventories must be physically verified from time to time.

The merchandise inventory is taken in two parts, the reserve (warehouse) stock and the forward (on-the-floor) stock. The count of the reserve stock presents no unusual problems. However, the count of the forward stock, which may include as many as two million separate items, is complicated by the requirement that no merchandise ready for sale should be tied up more than a few hours. The inventory is usually taken annually, as at The Emporium, and involves nearly every executive and regular employee in the store. It is, of course, necessary that the count be quite accurate, for the inventory figure is used for many accounting purposes, including the determination of total profits.

The forward inventory count is carried out by dividing each department of the store into sections and assigning a two-person team to each section. These teams may consist of regular store employees or temporary workers hired especially for the inventory. One member of the team calls information about the stock from the shelves, tables, bins, etc., and the other enters the items on the inventory sheet. The stock is listed by price, description, quantity, classification within the store, and season letter. This count is carried out under considerable time pressure. Prior to our investigation, a 100 percent check had always been made of all work performed in the forward inventory, as it was believed that such a check was necessary for reliable results. This 100 percent check nearly doubled the cost of the inventory and also nearly doubled the time required.

We analyzed the existing procedure to determine the possibility of substituting an acceptance/rectification sampling scheme for the 100 percent double check of the forward inventory. Such a procedure seemed feasible, since the errors that were presumably corrected in the 100 percent verification were those within the control of the inventory teams. Fortunately, information about the types, frequency, and severity of errors that had been discovered by the check inventory teams in past years could be obtained by examining the old inventory sheets. No corrections to inventory sheets have ever been permitted by erasure; every correction requires calling the inventory supervisor, crossing out the improper entry, and making the corrected entry at the bottom of the sheet. By examining the handwriting of the corrected entries, we could tell whether the correction had been made by the original team or by the checking team.

Some 3,000 inventory sheets from the previous year were analyzed in this manner. The analysis indicated clearly that a few teams were usually responsible for most of the errors made in any department. A large majority of the teams produced work of quite respectable accuracy. Large errors in price or quantity were infrequent, the most common errors being over or under one unit in physical count, one dollar off in price, or listing the wrong season letter. Different types of goods seemed to differ greatly in their liability to inventory error.

As a result of this analysis, we inaugurated an inventory sampling plan for the January 1950 inventory. (The 100 percent double check was maintained in a very few spots, particularly on lines of merchandise where an error in count would prove costly.) The inventory took place during two 4-hour periods from 6 to 10 p.m. following regular working days. The work of each inventory team was sampled by a "flying inspection squad" of experienced store employees. If the sample proved satisfactory, the entire night's output of the team was approved. If the sample contained too

many errors, the team was immediately notified of the fact and its procedure was closely observed; all of its previous work was checked 100 percent; subsequent work was sampled again (on a stricter basis) with the possibility of a future 100 percent check.

For the sampling procedure, we selected three different Dodge-Romig double-sampling AOQL plans. The plan to be applied to each department was selected on the basis of the analysis of the previous year's inventory sheets, giving weight to the type and value of merchandise and the probable number of inventory entries. In the use of the sampling tables, one line on the inventory sheet (typically representing ten to 125 items) corresponded to a single manufactured article subject to inspection; any error on the line caused its classification as a defective. However, a line that was correct except for an error in season letter was counted as only one-half a defective; this error affected neither the count nor the value of the merchandise, but only its estimated age distribution.

The sampling plans were selected having OC curves indicating that not more than 20 percent of the total work would be rejected and reinspected. This decision was an essential part of the planning of the inventory as it determined the number of reinspection teams to be provided.

The result of this inspection scheme for three different years is summarized in the following tabulation, showing for each year the number of teams inspected and the percent rejected:

Year	Number of Teams Inspected	Percent Rejected
1950	462	10.8
1951	463	12.5
1952	535	11.0
Total	1,460	11.6

For each of these three years the rejection rate varied within narrow limits, from a high of 12.5 percent to a low of 10.8 percent. The sampling procedure functioned smoothly, with no more than the anticipated number of difficulties. The substantial increase in teams inspected in 1952 was the result of adding departments that were previously checked 100 percent. As we became increasingly confident in the ability of the "flying squads" to single out the inefficient, error-prone teams, we 100 percent checked fewer and fewer of the departments containing expensive price lines.

Near the end of each inventory there were invariably a few idle teams. All inventory supervisors were instructed to use these idle teams in double-checking even though the work has been approved by the sample checks made by one of the flying squads. As a result of this instruction, a fair amount of approved work was double checked. In order to evaluate the efficiency of the sampling plan, we made a detailed investigation of the errors located in checking the approved work and contrasted them to those located in checking the rejected work.

This analysis proved conclusively that the sampling procedure had really succeeded in separating the inefficient teams from the efficient teams. In almost every case the double-checking of approved teams revealed only a bare minimum of errors, quite consistent with the AOQL used. The work of the rejected teams produced additional errors in over 90 percent of the cases examined. We found that, on the average, the approved teams counted about 30 percent *more* items in the same time period as the rejected teams, while committing less than one-fourth as many errors.

The store executives and auditors have been well pleased with this application of statistical sampling methods. The savings in direct labor costs were substantial (several thousand dollars annually). In addition, indirect savings resulted from the reduction in time required for the inventory.

CONCLUSION

The examples described represent only a few of the possibilities that exist in today's modern department store. Although our experiments have clearly demonstrated the potentialities of quality control, sample surveys, and other statistical procedures, we have thus far investigated only the more obvious applications. New techniques, as we all know, must advance slowly and soundly. We must gain the confidence of those involved, convincing them that the new procedure is superior to the old one. In the intensely competitive markets of today, only one answer really counts: Does the new procedure mean greater profits than the old one? This is the question that we asked at The Emporium. We are pleased with the answer.

Some Applications of Quality Control Techniques to Clerical Work

ROBERT B. SELOVER

The Prudential Insurance Company of America

INTRODUCTION

This article will describe two applications we have made of quality control to clerical operations. These examples will demonstrate that there are applications of quality control techniques to clerical work as well as to industrial production. Our experience convinces us that very real gains can be made in both the quality and economy of our work by application of quite common concepts and methods. Discussing these two examples of our work will point up some of the psychological principles used to encourage improvement. Effective applications of principles of learning and motivation have been made in these programs. Since these concepts have not been discussed previously they will be emphasized in this article.

DEVELOPMENT OF PROGRAM

Dr. Bennet Murdock first made application in our company of quality control techniques in June, 1949. This first attempt, applied to work

involved in making changes in life insurance policies requested by the insured, was so successful that many further programs followed. We have operated programs in 35 different work groups in 12 different divisions of the company. The applications have covered a variety of clerical work from simple repetitive tasks such as filing, to complex work such as underwriting and correspondence. Almost without exception improvement has been striking at first, followed by more gradual improvement. A graph of the percent of cases handled correctly appears much like a typical learning curve which improves rapidly at first followed by a more gradual increase. Much of what we do is to apply principles and methods which will facilitate learning.

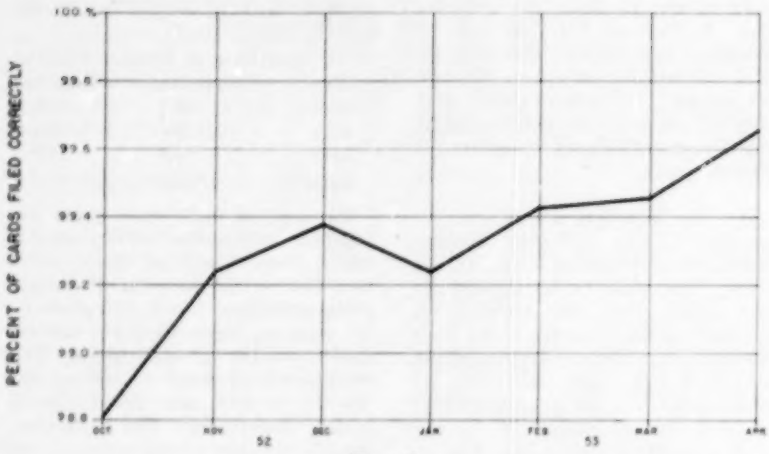

Figure 2

METHODS OF APPROACH

Although each application of quality control is different because of the nature of the work done, perhaps we can best explain how we make an installation by giving an example. There are several differences between our approach and the more commonly used methods in industrial quality control. First of all, we are primarily interested in improving the performance of people rather than controlling the quality of machines. It is for this reason that we refer to our work as quality improvement. Clerical work is either right or wrong and therefore we deal with attributes rather than variables. Mechanical means are generally not available to determine clerical accuracy and therefore we place great reliance on the inspector's knowledge and judgment. The inspection of work is made by one of the clerks, whom we call a Quality Reviewer, rather than by an outsider. We realize, of course, that disadvantages can result from this procedure but we feel that the advantages we gain are more important. Quality Reviewers are changed periodically so that each person in the section acts as a reviewer. Thus, each clerk has the opportunity to see the work of other members of the section and can learn from this experience. Employees frequently become more personally involved in the goal of improving the quality of work after they have had experience as a reviewer.

Figure 1 shows schematically how a program might operate in a typical section. Work comes into the section and is distributed to the clerical group. After the work is completed it is sent to a control desk. A representative sample of the work is taken from the control desk by the Quality Reviewer. This sample of work is then carefully checked for accuracy and completeness. A tally is made of the number and types of inaccuracies found. Error cases are sent to the supervisor who returns them for correction to the clerks who made the errors. The correct cases are returned to the control desk from which they leave the division along with the rest of the completed work. The error information is sent to the Quality Improvement Section where it is analyzed to determine significant changes which have occurred in the accuracy of the work and to determine, insofar as possible, the causes for the inaccuracies. If systematic errors are observed, the Quality Improvement Staff attempts to discover whether or not some of the processes, forms, source material or method operates to facilitate making the errors. Each week the results are tabulated by the Quality Improvement Section and distributed to the management in the division. Periodic reports containing analyses and suggestions are also prepared and sent to interested individuals. Each week a quality graph is prepared for distribution. This tells the story of improved quality at a glance, even though it may oversimplify progress. Each installation is, of course, different because of the nature of the work done and the methods used in processing the work.

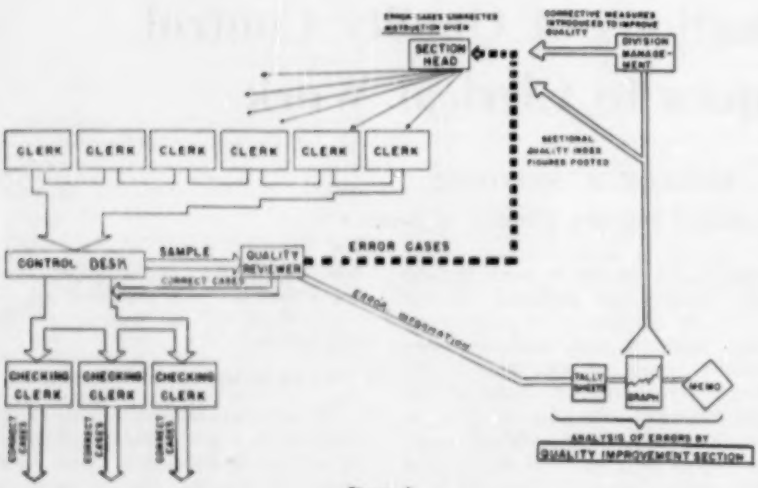

Figure 1

RESULTS

Typical results of a program are shown in Fig. 2. This program was carried out on a simple card filing

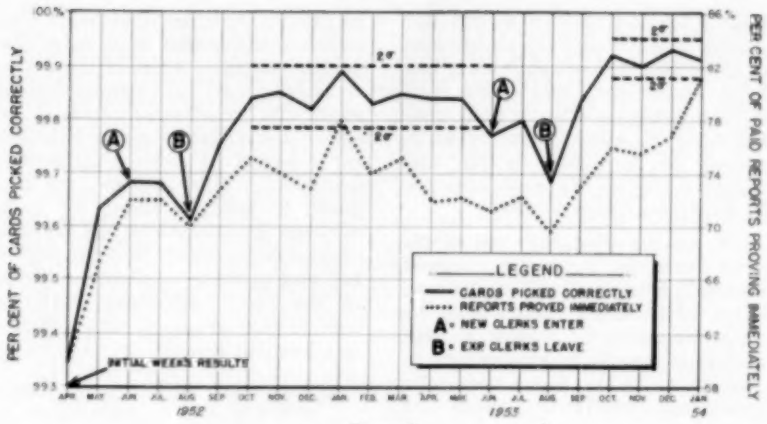

Figure 3

operation.* The cards in this file are used for reference to basic information about life insurance policies. A card is removed from the file and sent to another division when a change in the policy is requested. When the cards are returned they must, of course, be refiled. It is the accuracy of this refiling operation that is represented by the graph. Approximately 40,000 cards are refiled each week. The work is done as a part-time job by about 60 clerical employees each afternoon. The cards filed correctly started at 98 percent and improved to about 99.4 percent over a period of a half a year. The question arises as to the importance of this improvement to the division's operation. Since this was only one of several programs of quality improvement carried out in the division, an exact assessment of its contribution to the improvement is difficult. One indication is given, however, by the amount of time required to locate cards reported missing from the file. When a card cannot be located a special search is, of course, necessary. Before the quality improvement program was installed, this tracing operation required special personnel as well as supervisory time. Since the beginning of the program the amount of time spent in this tracing operation has reduced by about one half. This program was discontinued after seven months' operation because it appeared that further improvement should not be expected. A periodical review is made of the filing in order to assure ourselves of the continuation of the improved accuracy obtained by the program.

*This program and the one following were planned and supervised by Joseph Quade and Blair Olmstead, respectively, who are members of the Quality Improvement Section.

The second program we shall mention is also on a filing operation. In this case we are interested in the accuracy with which billing cards are picked in order to audit premium receipts received from our branch offices. These billing cards are punch cards which contain identifying information and the amount of premium which is due. The billing cards picked must agree exactly with the receipts received in order to prove the report.

After the cards have been picked they are sent to the machine room where a tabulator listing is made showing each premium due. Totals are shown for each district. This report is then returned to an audit clerk who compares this listing with the branch office report. If they do not agree, the audit clerk must determine why and arrange for the errors to be corrected. After an error is found, the correct billing cards are sent to the machine room and the report "rerun."

The program in this section was started on March 13, 1952. A summary of the results are shown in Fig. 3. The error rate at that time was 0.7 percent. At the present time the error rate is fluctuating between 0.1 and 0.2 percent. It is interesting to note the shape of the graph of improvement. One might expect that changes within such a small range of accuracy would be haphazard and perhaps defy explanation. However, each year there is a very large change of personnel in this section. We employ high school graduates during June and July and assign many to this work. People who have been in this section are moved on to other jobs. The quality of performance shows a very noticeable drop in August each year, which is apparently related to this change in personnel. Over the period of two years a significant improvement is evident. Although the change in the percent of cases handled correctly was small, it had a very marked effect on the number of reruns necessary in the machine room. The number of reruns required to prove the accounts has been reduced from about 40 percent in 1952 to slightly under 20 percent at the present time. This, of course, has greatly reduced time in the machine room to perform the operations.

DISCUSSIONS

There are several factors which we believe operate to produce the improvement we characteristically observe in these programs. These might be divided into two general classes. First, changes are made in methods and procedures which reduces the possibility of making an error. Second, principles of learning and motivation are introduced which encourage improvement.

In the first example presented, methods changes included improved physical condition of the file. An improved use of card notching was introduced which made it quite apparent when a card was misfiled in the wrong drawer. A more adequate presort was also introduced before the cards were refiled. In the second example, methods changes included improving the legibility of the billing card by changing the color border used, and improving the ink used in interpreting cards. The file itself was moved to a better location and the lighting and space improved. These changes, we believe, had a real effect in reducing the possibility of error in processing the work.

The principles of learning introduced in these programs are perhaps less readily identified but nevertheless important. First, just getting objective about quality, that is, defining it so that it could be counted, has an important effect. Quality then becomes something which can be observed, measured and plotted, rather than a nebulous, ill-defined but desirable characteristic. By measuring quality of performance, employees are shown in a very real way that management is genuinely interested in their producing work of high quality. If employees do not have that understanding, we can hardly expect them to be greatly concerned about their accuracy.

Learning is greatly facilitated by clear-cut goals toward which to work. Intermediate or sub-goals which can be attained within a

reasonable time are more effective in producing learning than distant and difficult goals. Measuring quality makes it possible to set up objectives which are within easy reach of employees and thus encourages improvement.

The importance of knowledge of results has been demonstrated in all kinds of learning situations. Studies have shown that in the absence of knowledge of results, extended practice produces little, if any, improvement. Further, it is found that immediate knowledge is most effective in facilitating improvement. As the time interval is lengthened between performing an operation and information about its correctness, learning becomes more difficult. Studies have also shown that the information given should be as definite and complete as possible. These basic concepts are encouraged by a program which reports quickly and accurately the kinds of errors that have been made. You perhaps have heard a supervisor say, "I told them exactly how many errors they made and they haven't improved in the least." Of course, one should not expect improvement in the absence of exact information about what was done incorrectly. Employees need to be given knowledge of their performance in exact terms. Results should be furnished quickly and automatically to be most effective in improving performance.

The results of quality are measured in terms of percent of cases handled correctly rather than a count of incorrect cases. This, we feel, emphasizes accomplishment and gives people an opportunity to develop pride in their work. No permanent individual records are kept, and by the way a program is installed and operated it is made clear that our objective is improving the quality of the work and not the evaluation of people. All of these factors we believe operate to produce the characteristic result we have observed.

SUMMARY

On the basis of our experience in applying quality control techniques to clerical work, we have learned to expect a substantial increase in the percent of cases handled correctly. A typical curve of improvement is negatively accelerated, that is, it shows first a sharp increase followed by a period of more gradual improvement. This increase, we believe, is brought about by both methods improvements and the use of procedures which facilitate learning and increase motivation. Some of the more important principles used in this approach which facilitate learning are:

1. measuring performance objectively so that meaningful goals can be established toward which to work,
2. giving immediate and exact knowledge of results of their performance to the clerical staff, and
3. expressing results positively, thus giving people encouragement to improve and take pride in the quality of their work.

What ASQC Has Done for Quality Control*

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It is interesting to note that as early as 1923 engineers in the Bell Telephone Laboratories and Western Electric Company were working on applications of probability theory and that in the same companies the first sampling tables were developed and put into use in 1926. These tables were not kept a secret, but ten years later you could still count on the fingers of one hand the companies that were using these techniques at all.

In fact in 1936, I happened to be in charge of factory training at our plant in Endicott. This included foremen training and as part of the course we sent young foremen to other plants where we knew they would be exposed to new ideas. I had heard that Western Electric had an "inspection system" that was new, so we decided to send an inspection foreman down to look it over. What did he report? Just what you guessed: "It can't be applied to our business!" Today, we use statistical methods in every inspection department in our business, and there are countless applications still to be made. This experience is no different from that of many others who have investigated the possibilities of these techniques for the first time.

During the war, I was Quality Control Officer for the Rochester Ordnance District and one of my duties was to visit contractors and interest them in statistical quality control. We had over 100 plants in New York State making everything from 30 caliber cartridges to tanks, and I did not find statistical quality control being used in any of them.

In my opinion, the promotion of the concept of statistical quality control started when the Ordnance Department sought the aid of the Bell Telephone Laboratories in training district personnel in these techniques for use in government acceptance inspection. This brought inspection by statistical means physically into thousands of plants in this country where its effectiveness was demonstrated. The ESMWT courses which followed capitalized on this kindled interest and ultimately resulted in the founding of the American Society for Quality Control.

It is a curious circumstance that an idea which is so fundamentally sound and which, in many respects, filled a vacuum that existed for many years in industry, could lie practically dormant for nearly 20 years. However, it will not be surprising to the people of the Bell Telephone Company. To quote an October 1876 copy of the *New York Herald Tribune* on the subject of the telephone:

"Of what use is such an invention? Well, there may be occasions of state when it is necessary

*This article is based on a presentation made before the Western Regional Conference ASQC, in Seattle, Washington, March 19, 1955.

for officials who are far apart to talk to each other, without the interferences of an operator. Or some lover may wish to pop the question directly into the ear of a lady and hear for himself the reply, though miles away; it is not for us to guess how courtships will be conducted in the twentieth century. It is said that the human voice has been conveyed by this contrivance over a circuit of sixty miles. Music can be readily transmitted. Think of serenading by telegraph!"

We look back and laugh at such stupidity and lack of vision, but are we so different? Is it not conceivable that today there are those among us with just as little ability to see the merit of a new idea?

How do you shorten the time it takes to make people see, how do you "spread the word"? It is done by men who have seen the value and proved to themselves by personal experience that these "new" ideas are sound and practical.

What has ASQC done for statistical quality control? I say it has been the instrument, the rallying point, the wellspring, that has made possible the exceedingly rapid development of this new technology.

It has bonded together persons of common interest in quality control and given them the determination to carry on in the face of apathy or opposition on the part of skeptics. There is something inspirational about hearing another's experiences and learning more about the fascinating things that happen in the world of applied probability. The backbone of our Society is the section meeting. It is there that we exchange ideas, discuss common problems, and go home reconfirmed in the soundness of the basic principles of SQC. If the Society did nothing more than bring together persons interested in quality control, it would serve the science well, but it has and will continue to do much more.

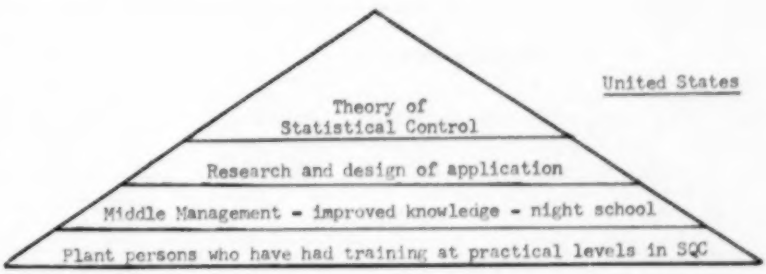
By being an important channel through which the statisticians' theories are reduced to practice in the many industries in the country, the Society has also served a worthwhile purpose. Through the practitioners have come the problems, and from the statisticians have come many of the solutions. There are many of both groups in our Society, and bridging the gap has been beneficial to all. In the management of the Society, we have tried to keep to the middle course; that we have succeeded is evident by the number of members we have today from the ranks of professors, statisticians, mathematicians, and the rank of inspectors, technicians and first line supervision. Our membership is open to all who are interested in quality control. We might be called a quasi-technical society because we do not require a degree for membership, and this has been good because it has brought into the Society many who might otherwise never have learned about SQC.

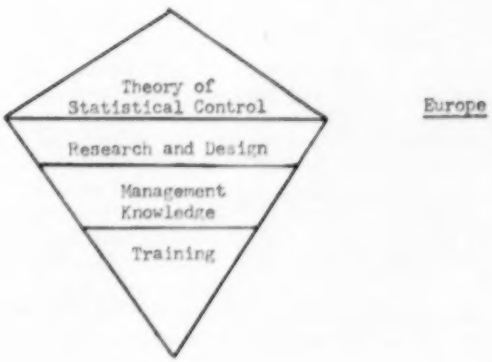
The phenomenal growth of ASQC has been accomplished without pressure, without commercialism, and without seeking a subsidy from industry. In the many years since its founding in 1946, it has been managed by men who have been very conscious of professional ethics, conservative of funds, yet adventurous to the end that today ASQC is firmly established as the leading society in quality control, and the publication, *Industrial Quality Control*, the leading journal in its field. Through meetings, conferences, and conventions, ASQC has promoted the use of statistical quality control in new fields. Many industries have learned about SQC for the first time at a gathering of our members or from one of the Society's publications.

It is interesting to compare the development of the science of quality control in this country with that abroad. Particularly impressive is a report from Professor Paul Clifford, who is now in Europe under the auspices of our government to assist foreign industries in applying SQC techniques. To quote:

"The programme in each country has been uniquely developed to meet the needs of that particular country. There seem to be three needs common in all countries. The first is a lack of comprehension on the part of management as to the functions and objectives of quality control in general. The second is the difficulty encountered in bringing the theory down to the operational level that plant personnel can comprehend. The third is the fact that in general no organizations devoted to quality control exist, and communication within a country and between countries is difficult. In each country the programme provided some approach to a solution of these three problems. However, the situation with regard to the level of technical ability within the various countries varied considerably, and the particular type of training programme developed took into account these differences in level.

It is not feasible to compare the relative status of quality control in America and Europe. In the European countries a great deal of attention has been devoted to the theory of statistics and con-


United States
Theory of Statistical Control
Research and design of application
Middle Management - improved knowledge - night school
Plant persons who have had training at practical levels in SQC



trol, without much attention being paid to the training of plant personnel. In many meetings this has been illustrated by two pyramids, the first representing the situation in the United States and the second the situation in many European countries. It will be seen that the broad supporting base sections that exist in America need to be created in Europe."

In my opinion, the "broad supporting base sections" in the United States were made possible by the promotional efforts of our Society. We have been able to serve our members well and promote successfully the extension of SQC because the management of our Society has always been sensitive to the needs of our members. Practically our entire budget of nearly $100,000 annually goes into service to our membership. Much of this money has gone into publication of basic material specifically aimed at the beginner and non-technical practitioner looking, not for theory, but for the ways in which he can apply this new tool. Contrast this with the articles published in other countries where the theorist writes for the enlightenment and acclamation of other theorists. That we have chosen to regard SQC as a tool rather than another extension of the field of statistics has, in my opinion, been an important distinction.

There have been pressures by various segments of the Society to elevate the professional status of our membership by more restrictive qualifications, and to steer our publication policy to a higher level. Although I want our "new profession" as ardently as anyone to someday achieve its full stature, I do not believe that that time has yet come. There are still too many industries that are not using SQC. I believe it should be many years before we abandon the "open door" policy that has contributed so much to building the bridge between the theory and practice of our profession.

Today, we are at a new threshold in our development: we have grown to the point where we are developing divisionalization within the Society. Although the basic principles of SQC are equally applicable in the manufacturing of textiles, the building of an electronic computer, or the checking of invoices, there are being developed techniques in each field that make it desirable for those having a common interest to join together so that they may exchange ideas and develop their particular field further. In recent months, this has led the management of the Society to pave the way and encourage the establishment of divisions in the administrative, electronics, aircraft, automotive and other fields.

The success of our venture in the textile and chemical fields leads us to feel that the worth of membership in ASQC will be increased manyfold as our members are able to associate themselves more closely with others having similar interests.

Finally, I should like to suggest that we plan to extend the use of SQC in industry by soliciting new members from shop personnel and first line operating management by giving these groups primary consideration in section program planning, in conferences and conventions, and in our publications.

I also believe we should do more to recognize accomplishment in the field of the application of SQC. Once we have built this broad supporting base, we can then seek to elevate the professional status of membership, promote advanced techniques, and publish articles of a more scientific nature.

The Technique of Regression Analysis

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I. INTRODUCTION

Industrial problems are often concerned with the study of the relationship between two or more different variables. Typical questions of this nature might be:

If catalyst temperature is raised, will output be improved?

How does speed affect the wear on tires?

Is corrosion a function of concentration of inhibitors?

Is noise correlated with thickness of material?

Is knowledge of thickness of a weld helpful in predicting its strength?

Would the prediction be improved with the addition of hardness values?

How do the combinations of oil pressure, oil temperature, speed and load affect output horsepower?

Not infrequently measurements cannot be made directly but must be calculated from a line or curve between two variables; many coefficients and moduli are found in this manner. A precise calibration curve is needed. Theory indicates a certain physical law; experimental work is done to substantiate this theory; how well do the data do this? A prediction formula is needed.

Regardless of the field of application, such problems can be handled very nicely by the statistical technique called *regression analysis*. This technique gives not only the relationship between variables but also how good the relationship is.

The purpose of this article is to present the steps in the procedure in regression analysis in such a way that you will be able to apply it on your own problems; to discuss the more general aspects of the subject; and finally, to present a sufficient number of actual examples to indicate the scope of its usefulness.

There has been a great deal of elegant theory developed on regression and it is still by no means a finished subject. A rather extensive list of references is given for the reader who is seriously interested in pursuing the subject further. This is necessary for extensive use to avoid possible pitfalls. The more glaring ones will be pointed out in this article. References (2), (3), (9), (11) and (14) are recommended for the more simple treatment; (1), (12) and (13) are somewhat more advanced.

II. STEPS IN REGRESSION ANALYSIS:

a. An Example

One small phase of a development program was the determination of the effect of the iron content on the

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corrosion resistance of 90/10 copper-nickel alloys in sea water. Seven specimens, each containing a particular iron content, were tested in a corrosion-wheel setup. The wheel was immersed in sea water and rotated at 30 ft/sec for 60 days. The corrosion was measured in weight loss in milligrams/sq decimeter/day. The data obtained were as shown in Table I.

Table I

Iron Content, (%)	0.01	0.48	0.71	0.95	1.19	1.44	1.96
Corrosion (MDD)	127.1	124.0	110.1	103.9	86.8	99.2	83.7

How the data were collected, statistically speaking, is an important point. Some discussion of this subject will be given later.

The measurement under study in a regression analysis is called the *dependent variable*, usually expressed by the letter Y. In this problem, Y would be the measurements of corrosion in weight loss in milligrams/sq decimeter/day. The one or more other variables whose variations may be causing changes in the dependent variable are called *independent variables* denoted by X or X_i respectively. This problem is the simplest case involving only one independent variable, that is, percent of iron content.

b. Steps in the Procedure

Step 1:—The first step in determining the influence of iron content on corrosion would be to plot the data, the scattered points in Fig. 1. Such a plot would suffice for some situations.

However, for this case it is desired to measure quantitatively the effect, if any, of iron content on corrosion.

This plot appears to indicate the simplest type of relationship, namely a straight line. The general expression for representing a straight line is $Y = \alpha + \beta X$. For this problem Y is the weight loss and X the percent iron content; α represents the value of Y when $X = 0$, the *intercept* of the line; and β is the slope of the line, called the *regression coefficient*. Thus β is the change in Y for a unit change in X. Here it would appear to be the decrease in weight loss with a unit increase in iron content. Since our experiment consists of only a sample of observations from a population of an infinite number of observations, we can only estimate the parameters α and β and so we use "a" and "b" respectively for the estimated regression $Y_e = a + bX$. "a" and "b" can be found by the method of "Least Squares." This method gives the line that makes the sum of squares of the deviations of observed Y's from the estimated Y's a minimum. In other words we wish $\Sigma(Y - Y_e)^2$ to be a minimum.

Step 2:—We will now proceed to find this "best" line. At this stage formulas only will be given, neglecting the details of their development. These can be found in the references. In particular, refer to Chapter 4; Ref. 11.

$$b = \frac{\Sigma(Y - \overline{Y})(X - \overline{X})}{\Sigma(X - \overline{X})^2} \qquad (1)$$

$$a = \overline{Y} - b\overline{X} \qquad (2)$$

where $\overline{Y}$ and $\overline{X}$ are the mean values of the measurements of our two variables.

The following sums are needed to fit the straight line:

ΣY, ΣX, $\Sigma(Y - \overline{Y})(X - \overline{X})$, $\Sigma(X - \overline{X})^2$, and $\Sigma(Y - \overline{Y})^2$

Using our seven pairs of data: $N = 7$

$\Sigma Y = 734.8$, $\overline{Y} = 104.97$

$\Sigma X = 6.74$, $\overline{X} = 0.9629$

The short cut methods for the remaining are:

$$\Sigma(Y - \overline{Y})(X - \overline{X}) = \Sigma XY - \Sigma X \Sigma Y / N$$

$$\Sigma(X - \overline{X})^2 = \Sigma X^2 - (\Sigma X)^2/N, \text{ etc.}$$

Thus:

$$\Sigma(Y - \overline{Y})(X - \overline{X}) = (127.1)(.01) + (124.0)(.48) + \ldots + (83.7)(1.96) - \frac{(734.8)(6.74)}{7} = -59.648$$

$$\Sigma(X - \overline{X})^2 = (.01)^2 + (.48)^2 + \ldots + (1.96)^2 - \frac{(6.74)^2}{7} = 2.4787$$

$$\Sigma(Y - \overline{Y})^2 = (127.1)^2 + (124.0)^2 + \ldots + (83.7)^2 - \frac{(734.8)^2}{7} = 1695.19$$

Then substituting in formula (1) above,

$$b = \frac{-59.648}{2.4787} = -24.0642.$$

Before using the estimated straight line we should find out how well it fits the data. This will be the next step.

Step 3:—The analysis of variance is a very useful technique to determine whether or not the fitted line accounts for a significant part of the spread in the Y readings. In other words, it will answer the question "Does this line furnish a better means of estimating Y than the simple average?" The total sum of squares of Y may be partitioned into two parts, the first, with one degree of freedom, associated with the regression of Y on X or the sum of squares due to the regression) and the second, with $(N-2)$ degrees of freedom, associated with the variation of Y around the regression line.

Two additional formulas are needed for the sum of squares of the deviations in Y explained by the regression, and for the sum of squares unexplained.

$$SS_{regr.} = b\Sigma(X - \overline{X})(Y - \overline{Y}) \qquad (3)$$

This becomes $\dfrac{[\Sigma(X - \overline{X})(Y - \overline{Y})]^2}{\Sigma(X - \overline{X})^2}$

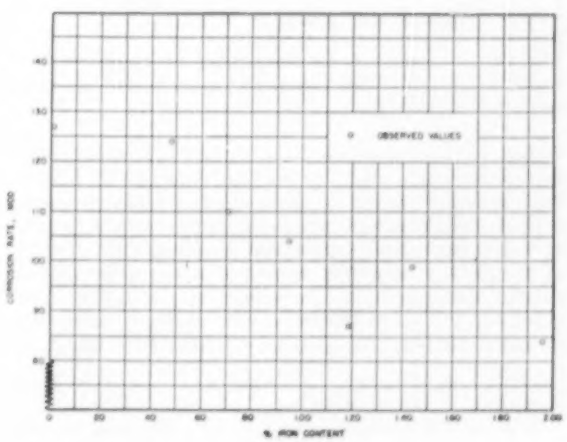

Figure 1

The unexplained sum of squares becomes

$$\Sigma(Y - Y_c)^2 = \Sigma(Y - \overline{Y})^2 - b\Sigma(Y - \overline{Y})\ (X - \overline{X}).$$

The summary table is modelled by Table II.

Table II

Source of variation	Degrees of freedom	Sum of squares
Explained by linear regression	1	$b\Sigma(Y - \overline{Y})\ (X - \overline{X})$
Unexplained	N-2	Difference $= \Sigma(Y - Y_c)^2$
Total	N-1	$\Sigma(Y - \overline{Y})^2$

Carrying through the arithmetic:

$$b\Sigma(Y - \overline{Y})\ (X - \overline{X}) = (-24.0638)\ (-59.648) = 1435.38$$

$$\Sigma(Y - Y_c)^2 = 1695.19 - 1435.38 = 259.81,$$

which leads to Table III.

Table III

Source of variation	Degrees of freedom	Sum of squares	Mean square	F
Explained by linear regression	1	1435.38	1435.38	27.62
Unexplained (deviation from regression)	5	259.81	51.96	
Total	6	1695.19		

We find the F ratio, explained/unexplained mean square, 27.62 by using the usual F tables, [10] to get the probability that so large an F would be due to random sampling only.

Here the probability, P, for so large an F is less than 0.01. A small P-value indicates that the straight line accounts for a significant part of the variation in the Y readings. Thus it is indicated that a significant part of the variation in weight loss (corrosion) of the seven specimens can be accounted for by the difference in their iron content.

A meaningful value would be the percent of the total variation in the seven readings which is explained by the straight line. This is

$$\frac{\text{SS (expl)}}{\text{SS (total)}} = \frac{1435.38}{1695.19} = .85 \text{ or } 85\%$$

This value happens to be the square of the correlation coefficient, or r^2. The value, 85 percent, measures the efficiency of the line.

Step 4:—The next step in this procedure would be to determine if the efficiency can be improved by including a quadratic term. In other words, we have assumed a linear relationship but would better results be obtained if we used a curvilinear relationship? A study of the plotted data (Fig. 1) would seem to indicate no curvilinearity present. However, for illustrative purposes, we will carry through the necessary computations to make this test. The general expression for this is:

$$Y = a + b_1X + b_2X^2 + \ldots b_nX^n \qquad (4)$$

In solving a quadratic or cubic, etc., the least squares criterion leads to a set of simultaneous equations. The setting up of these so-called normal equations is quite systematic. If the equation to be fitted is written in the form

$$Y - \overline{Y} = b_1(X - \overline{X}) + b_2(X^2 - \overline{X^2}) + b_3(X^3 - \overline{X^3}) + \ldots$$

much computational labor can be saved.

Since we are fitting the quadratic, only two simultaneous equations are needed. The first is obtained by multiplying the equation above (with terms of degree 3 or greater discarded) by the first independent variable $(X - \overline{X})$. The second is obtained by multiplying the equation by the second independent term $(X^2 - \overline{X^2})$. The resultant products in each case are then summed over all the data points giving the simultaneous equations:

$$b_1\Sigma(X - \overline{X})^2 + b_2\Sigma(X - \overline{X})\ (X^2 - \overline{X^2}) = \Sigma(X - \overline{X})\ (Y - \overline{Y}) \qquad (5)$$

$$b_1\Sigma(X - \overline{X})\ (X^2 - \overline{X^2}) + b_2\Sigma(X^2 - \overline{X^2})^2 = \Sigma(X^2 - \overline{X^2})\ (Y - \overline{Y}) \qquad (6)$$

We will need the following additional sums:

$$\Sigma(X^2 - \overline{X^2})\ (X - \overline{X}),\ \Sigma(X^2 - \overline{X^2})^2 \text{ and } \Sigma(X^2 - \overline{X^2})\ (Y - \overline{Y}).$$

The short-cut methods, as before, are appropriate here. Computing these sums and substituting in the preceding equations (5) and (6) gives

$$2.4787b_1 + 4.8913b_2 = -59.648$$
$$4.8913b_1 + 10.6944b_2 = -113.4118$$

Solving these two simultaneous equations gives

$$b_1 = -32.1918$$
$$b_2 = 4.1188$$

The expression for "a" would be: $a = \overline{Y} - b_1\overline{X} - b_2\overline{X^2}$, but before computing this we will want to determine if there has been a significant improvement in efficiency by adding the quadratic term.

Step 5:—To determine this efficiency we again use the analysis of variance technique, noting that here

$$\Sigma(Y - Y_c)^2 = \Sigma(Y - \overline{Y})^2 - b_1\Sigma(X - \overline{X})(Y - \overline{Y}) - b_2\Sigma(X^2 - \overline{X^2})(Y - \overline{Y}).$$

See Tables IV and V for details.

Table IV

Source of variation	Degrees of freedom	Sums of squares
Explained (regression)	2	$b_1\Sigma(X - \overline{X})(Y - \overline{Y}) + b_2(X^2 - \overline{X^2})(Y - \overline{Y})$
Unexplained (dev. from reg.)	N − 3	Difference $= \Sigma(Y - Y_c)^2$
Total	N−1	$\Sigma(Y - \overline{Y})^2$

Table V

Source of Variation	Degrees of Freedom	Sum of squares	Mean square
Explained by regression	2	1453.06	
Unexplained (dev. from reg.)	4	242.13	60.53
Total	6	1695.19	

The improvement due to the quadratic term will be the difference between the sum of squares explained by the quadratic (Table V) and that explained by the linear only (Step 3). See Table VI for details. The measure of improvement is then compared with the estimate of random error, here the unexplained by quadratic mean square above, viz 60.53. We do not need to calculate F in this case since the improvement mean square 17.68 is less than the random error 60.53. This means that the quadratic did not give any improvement over the linear. Thus we conclude that the straight line is not only significant but also sufficient. We return now to the results of Step 3 to extend them.

Table VI

	Degrees of freedom	Sum of squares
Explained by linear and quadratic	2	1453.06
Explained by linear only	1	1435.38
Improvement with quadratic term	1	17.68

Step 6:—We now calculate the "a" for the linear relationship,

$$a = \overline{Y} - b\overline{X} = 104.97 - (-24.0642)\ (.9629) = 128.14$$

and present the relationship as

$$Y_c = 128.14 - 24.0642X \qquad (7)$$

Thus, when $X = 0$, $Y_c = a = 128.14$;
when $X = 1$, $Y_c = 104.08$.

Using these two points, the line is drawn (See Fig. 2.) As a check, the line should go through the point (X, Y). The constant value, a = 128.14, (Y intercept) gives the corrosion when iron is not present; b = −24.06 is the slope. The negative sign indicates a decreasing effect. Thus, for every one percent change in iron content, there is a corresponding decrease in corrosion of 24.06 MDD. This measure of the rate of change in corrosion for a unit change in iron content is called the "regression coefficient."

Step 7:—The unexplained mean square for the linear case, since the quadratic was not significant, is our best estimate of the random error-variance. In this case it is 51.96 from Step 3 above. The square root of this is the well-known standard deviation, called s since it is an estimated value. Hence

$$s = \sqrt{51.96} = 7.21$$

From the analysis of variance form (Table III) in Step 3,

$$s = \sqrt{\Sigma(Y-Y_c)^2/(N-2)} \qquad (8)$$

This value is also called "standard error of estimate." Then the standard error of the estimated regression coefficient, b, will be:

$$s_b = s/\sqrt{\Sigma(X-\overline{X})^2} \qquad (9)$$

Knowing its standard error, it is possible to compare an estimated regression coefficient with a hypothetical value or with another estimated regression coefficient.

The formula for the standard error of the estimated *regression line* will be:

$$s_{Y_c} = s\sqrt{1/N + (X-\overline{X})^2/\Sigma(X-\overline{X})^2} \qquad (10)$$

This is the error in predicting the *mean* of the dependent variable Y at a particular value of X.

To make a confidence statement about a *specific* Y, instead of the mean of Y, at a particular value of X, we use the following standard error: (p.120; Ref. 14)

$$s_Y = s\sqrt{1 + 1/N + (X-\overline{X})^2/\Sigma(X-\overline{X})^2} \qquad (11)$$

Using these standard errors it is possible to give "confidence" limits or "fiducial limits" about the estimated regression coefficient, the estimated regression line, and an individual with a particular X-value. Reference 14 (Sec. 6.9) is recommended reading for a clarification of these formulas.

Consider the estimated regression coefficient −24.06 in our example. For 95 percent confidence limits, the t-table would be entered with five degrees of freedom, and t read from the P=.05 column. This value of t is 2.57. The .95 confidence limits for b would then be

$$b \pm ts_b = -24.06 \pm 11.80.$$

For the estimated regression line, confidence intervals must be computed for each value of X. The nearer X is to its mean value, the narrower will be this band. To illustrate the computation, consider X = 1.96. Substituting in Eq. (10) above and multiplying by t gives:

$$\pm (2.57)(7.21)\sqrt{1/7 + (1.96 - .96)^2/2.4787} = \pm 13.6$$

Using the estimated regression line,

$$Y_c = 128.14 - 24.06 \times 1.96 = 81.0.$$

Hence the confidence limits for average at this value of X are 81.0 ± 13.6 = 67.4 and 94.6.

For the individual Y at this same value of X, 1.96, we would substitute in Eq. (11), obtaining

$$\pm (2.57)(7.21)\sqrt{1 + 1/7 + (1.96 - .96)^2/2.4787} = \pm 23.0.$$

Thus, while the population mean corrosion for this alloy with 1.96 percent iron content is probably between 67.4 and 94.6, any randomly selected specimen with this percent iron content may be found to have a corrosion rate anywhere between 58.0 and 104.0. This wide range bears out Snedecor's statement that, "predicting the performance of individuals, especially of those in the outer fringe, is a hazardous venture——."

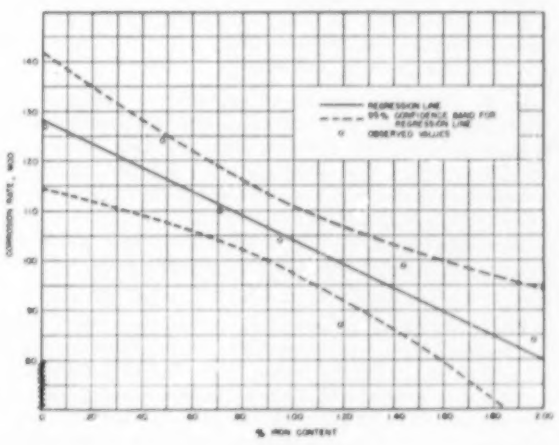

Figure 2

Thus far, we have covered only the essentials in doing a regression analysis. We have tried to give sufficient references for a study of the finer points. Generally we have followed the notations used in reference (11).

III. EXTENSION OF THE REGRESSION PROCEDURE

a. All the necessary steps for carrying through any regression analysis are to follow. To recapitulate, we started with the simplest case (a straight line relationship) $Y = a + bX$, showing the steps in computing the best line and testing its significance. Then a quadratic term was introduced and a test made of its adequacy. Similarly, it was mentioned that the procedure can be extended to include additional polynomial terms —cubic, quartic, etc.—for increasing degrees of "curvilinear" regression.

b. Finding the relationship of a dependent variable to more than one independent variable is simply a special case of Eq. (4) where the other independent variables X_2, X_3—appear in the place of the X^2, X^3, etc. The form then becomes

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3 + \ldots$$

This is called "multiple" regression.

Thus we have the designations "linear," "curvilinear," and "multiple" regression with the b's called the "regression coefficients." Each b measures the rate of change in Y, the dependent variable, for a unit change in its corresponding independent variable.

The procedure for fitting and testing the significance of the regression remains the same for all. Thus, for the multiple case, X_1 and X_2 would replace X and X^2 and we have:

$$b_1\Sigma x^2_1 + b_2\Sigma x_1x_2 = \Sigma x_1y$$
$$b_1\Sigma x_1x_2 + b_2\Sigma x^2_2 = \Sigma x_2y$$

where the lower case letters are used purposely here to indicate that the variables are measured from their mean values; that is, $x_1 = (X_1 - \overline{X}_1)$, $x_2 = (X_2 - \overline{X}_2)$ and $y = (Y - \overline{Y})$. (Chap. 8; Ref. 11.)

The normal equations for three variable cases are given in Section V.

It is clear that with an increase in the number of terms, or independent variables, the arithmetic becomes laborious. Schemes for systematizing the computations will be found in the references; (2) and (4) are particularly recommended for this. The scheme we use will be shown in Section V, c.

c. As a special case in fitting polynomials, it is advantageous to have the settings of the independent variable equally-spaced and the same number of readings at each setting. When this is true, a large amount of computing time can be saved since it is unnecessary to solve the simultaneous equations. In addition, and more important in some problems, the linear, quadratic, cubic, etc. effects are obtained independently of each other and can therefore be tested for significance.

The orthogonal polynomial technique is used here. This technique is relatively simple, the formulas being similar to those for the linear form. Tabular values are used in place of the X values. Tables for this purpose are in Refs. (7) and (10). The steps in the arithmetic are detailed in Ref. (6). An example of this is described in Section V.

d. No discussion of regression would be complete without at least mention of the analysis of covariance. We have seen how the analysis of variance technique is an integral part of regression analysis. Conversely, regression techniques can be an important adjunct to the analysis of variance. This entire development is due to R. A. Fisher.[9]

Due to physical limitations it may not be practicable or possible to keep certain variables (not under test) in control. For example, in comparing weathering resistance of different paints, the amount of paint applied may vary. Or it would not pay to build a constant temperature room for studying thermal rise in electric motors. Planned experiments on a production line must usually be run without having all variables under control. Original specimens used in testing may vary from specimen to specimen in size, weight, etc.

The analysis of covariance is a means of equalizing the influence of these variables, or uncontrolled conditions, provided they are measurable. A comprehensive treatment of this subject would yield an article in itself. References (5), (9), (11) and (14) are recommended reading here.

e. Another extension of regression analysis in the analysis of variance technique can result in more definitive information. When a factor in the analysis of variance is at different levels that are quantitive, its degrees of freedom can be divided into linear, quadratic, etc., components. Examples in Sec. V will illustrate this.

IV. DISCUSSION

a. The selection of the dependent variable in a regression analysis is usually by a "cause" and "effect" relationship. The independent variable would be the "cause" and the dependent would be the "effect." However, the independent variable may not necessarily be a casual variable. For example, the independent variable may be many variables removed from the direct cause. The results would then be interpreted with this in mind. Perhaps no cause and effect relationship is even postulated. Then the criterion may become the use that is expected to be made of the analysis, etc. However, in these situations the difficulty in selection of independent and dependent variables causes us to be wary of our interpretation of the results.

Thus, regression coefficients, b, and the square of the correlation coefficient, r^2, are obtained in all of our regression problems as a matter of routine. However, the use and interpretation of the values differ from problem to problem depending on the physical situation.

When the variables may be of a "cause and effect" type, directly or indirectly, both coefficients are useful. The regression coefficient, measuring the change of the dependent variable per unit change of the independent variable, gives the quantitative effect of the cause. The coefficient r^2, measuring how much of the variation in the dependent values is explained by the use of the regression coefficient, gives the degree of the cause on the effect.

As the variables depart more and more from a "cause and effect" relationship, the interpretation of the regression coefficient, except for the sign, loses its importance. The r^2 value then is simply a measure of how well the two sets of data move jointly, that is how closely they are correlated. Thus regression contains the idea of a dependent variable with one or more independent variables while correlation does not contain the notion of dependency (page 122, Ref. 11). Quoting from Fisher

(art. 25, Ref. 9) "The idea of regression used usually to be introduced in connection with the theory of correlation, but it is in reality a more general, and a simpler idea; moreover, the regression coefficients are of interest and scientific importance in many classes of data where the correlation coefficient, if used at all, is an artificial concept of no real utility." Chapter VI of reference (9) and Chapter 7 of (11) are suggested reading in exploring the subject of correlation.

b. The settings or values of the independent variable may be either arbitrarily or randomly selected, or as measured. There may be one measurement of Y for each X value, an equal number, or a variable number of Y's for each X value.

c. As previously stated, a very important assumption in the formulas used is that the independent variables shall be free from error. This can be relaxed to "relatively free from error" as compared to the error in the dependent data which are the subject of study. It is important to note that the deviations from the line in the example (Section II) are vertical distances, that is, deviations of Y values. This follows from the assumption that only Y is in error, X being relatively free from error. If the opposite situation existed, the Least Squares criterion would give a slightly different line, since we would be minimizing horizontal distances. The formulas would be similar except for interchanging X and Y. Thus there are two regression lines possible, Y on X and X on Y. Between these two extremes, vertical and horizontal, there are various approaches, depending upon our knowledge of the errors in both X and Y variables. (The r^2 values will be the same for Y on X as for X on Y.)

Often, if both Y and X are measured, there will be a definite error in determining X. In the use of a small sample, the estimate of the regression coefficient will be biased. The bias introduced generally reduces the absolute value of the regression coefficient. In this connection Yates[15] makes the following statement: "Errors in the independent variates do not affect the validity of the ordinary tests of significance, provided that only differences from zero are being tested, and the coefficients as ordinarily evaluated will always be the best coefficients for the purpose of prediction from subsequent observations subject to similar errors." Deming[8] gives a detailed treatment of this subject.

d. Frequently there is another measure of the random error involved in the dependent variable besides the error from regression. This usually comes about from running replicates at each value of the independent variable. Then, comparison of these two measures of error would be very informative.

Using our example as an illustration, if two concentrations had been made, i.e., from different mixes, there would be a measure of error independent of the regression. If the mean square from regression were significantly larger than this experimental error, the inference would be that the relationship can still be improved, perhaps with a different type of curve. Should the experiment error happen to be significantly larger than regression error, then it would certainly be time to start looking at the details of the test setup.

It is worthwhile to call attention to the fact that this experimental error is not derived from pairs of readings on the same specimen, say duplicates. The duplicate error would only be a measure of the reading error and as such is not an estimate of a true experimental error.

Along this vein, it is vital that randomness enter into the testing at many stages. This is, of course, necessary to prevent any systematic effect from distorting the results. For example, suppose in our problem, the heat treatment was given to the various slabs in an orderly fashion. The material containing the lowest iron content was heat-treated first, second lowest treated second, etc. A question would then arise as to how much of the effect that we were attributing to iron content was actually due to temperature regulation in the heat treatments.

e. Since generally the data in a regression analyses will be a sample, usually small, predictions therefrom will be subject to the same limitations and pitfalls inherent in the single-variable case. Thus all predictions are based on the assumption that future conditions will be the same as those present when the original data were taken. Also predictions are valid only within the range of the settings or measurements of the data on the independent variable.

f. In addition in making use of the analysis of variance technique, we must assume that the errors of our experiment, that is those in measuring corrosion rate are

(a) normally distributed with mean zero
(b) independent
(c) of equal variance for the several settings of percent iron content.

V. PROBLEMS INVOLVING REGRESSION ANALYSIS

A few actual examples of the uses made of regression may be helpful.

a. Calibration Problem in Linear Regression.

The Chemical Engineering Laboratory of the Station was interested in the use of the infrared spectrograph in place of the time-consuming chemical methods in the determination of additive content in Diesel engine oils. A calibration curve of concentration and density was needed for the particular wavelength to be used. It was important to know the error in the calibration curve for comparative purposes.

There were some especially interesting aspects to this example which will be brought out in the discussion.

The experimental data consisted of from two to eight readings of density (Y) at each of eight concentrations (X), making a total of 37 items.

The analysis of variance for these data gave the summary shown in Table VII.

Table VII

Source of Variation	Sum of Squares	d. f.	Mean Square
Between Concentrations	.72011010	7	.10287280
Within Concentrations	.00169475	29	.00005844
Total	.72180485	36	

Since the concentration factor was one with quantitative settings, the seven degrees of freedom were further divided by regression analysis. A straight line was found to be adequate. It was:

$$\text{Density} = .00465 + .0147 \text{ Concentration } (\%)$$

The corresponding analysis of variance is summarized in Table VIII.

Table VIII

Source of variance	d. f.	Mean Square	F
Explained by linear	1	0.720033	56,030 highly significant
Deviation	6	.00001285	2.2 not significant
Between concentrations	7		
Within concentrations	29	.00005844	
Total	36		

That the "deviation" from the straight line was not significantly larger than "within concentrations" indicated that the straight line was an adequate mathematical expression of the relationship. A quadratic term was tried, but the test of significance indicated no improvement. This verified the accepted theory that the relation should be linear (Beer's Law). It is important to point out that the "within concentrations" were from density readings at the same percentage concentration, but on different solutions, i.e., made up on different days.

Beer's Law was therefore assumed to hold in calibrating the instrument again after its periodic cleaning. In later testing, this assumption led to only two concentrations being tested; the lowest and the highest percentage in the zone in which we were interested. As reference (4) points out, these are the most efficient settings in determining the straight line. The saving in testing to determine the straight line permitted an incorporation of a study of other factors: preparation, stability, variable drive. The method of covariance was used in this later study to take into account input voltages and operating temperatures.

Consider the calibration line we obtained which was to be used in predicting the concentration from the density readings. Since we were predicting the independent variable, we were interested in the error of this prediction, a switch-about from the usual situation. This required a refinement in the error formula. Reference (1), page 133 gives the variance of this prediction as:

$$\text{Variance (X)} = \frac{s^2}{b^2}\left(\frac{1}{m} + \frac{1}{N} + \frac{(Y-\overline{Y})^2}{b^2\Sigma(X-\overline{X})^2}\right) \quad (11)$$

where Y stands for density, X for concentration, and m the number of readings at any particular point.

b. Fitting by Orthogonal Polynomials.

This study concerned the relationship of output frequency to load in the Vickers 10 KN Motor-Generator set. This generator set was a new design sent to the Electrical Laboratory for testing to specification requirements. Because the project engineer was interested in studying its overall characteristics, statistical planning was used. The analysis of variance indicated that load, one of the main effects, was a significant factor on output frequency.

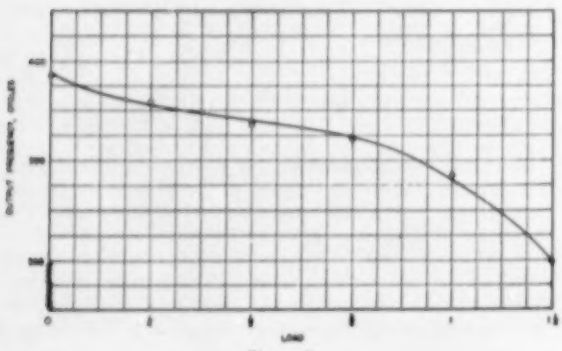

Figure 3

With load as the independent variable and output frequency the dependent, the data were plotted as in Fig. 3. This figure indicated a somewhat rapid decrease in output frequency with the addition of load, then a slackening in this decrease but followed at the higher load with an accelerated change. An important part of this problem was to find the algebraic values for the relationship, which appeared to be a polynomial. The load settings had been selected at equal intervals. This meant that the orthogonal polynomial method of curve fitting could be used, (Section III, c above). The worksheet was as shown in Table IX.

Table IX

Output Frequency Y	Load X	Orthogonal Values E'1	E'2	E'3
399.83	0	−5	+5	−5
399.58	¼	−3	−1	+7
399.36	½	−1	−4	+4
399.20	¾	+1	−4	−4
398.84	1	+3	−1	−7
397.98	1¼	+5	+5	+5
		70	84	180

The last three columns with the corresponding sum of squares at the foot of each column were copied from Ref 10, Table XXIII, N = 6. These tables give the transformation values for N = 3 to N = 52 and go as high as the fifth degree.

In fitting

$$Y = \overline{Y} + b'_1 E'_1 + b'_2 E'_2 + b'_3 E'_3$$

we only had to find three additional sums, $\Sigma E'_1 Y$, $\Sigma E'_2 Y$, $\Sigma E'_3 Y$.

The analysis of variance in Table X indicated that the third degree was sufficient.

Using the formula, Ref. 10,

$$b'_i = \Sigma E'_i Y / E_i^2$$

we obtained:

$$Y = 399.13 - 0.16614E'_1 - 0.04298E'_2 - 0.01906E'_3$$

To obtain the sum of squares explained by each term we used the formula, Ref. 10,

$$\text{SS explained by "i" term} = b'_i \Sigma E'_i Y$$

Since the orthogonal polynomial method was used, each estimated effect was independent. Thus, from the analysis of variance table the first degree was significant at the .01 level of probability (F-value in column (4) compared with those in columns (5) and (6).) The F-value for the second degree term was less than that required for .05 level. The F-value for the third degree was well over the .05 level requirement. This was considered sufficient, since the residual mean square .0021 was of the same order of magnitude as was the experimental error variance of the test.

Table X

Source of variation	(1) df.	(2) Sum of squares	(3) Mean square	(4) F	(5) Probability levels from ref (10) .05	(6) .01
Total	5	2.1569	—	—	—	—
Degree 1	1	1.9322	1.9322	34.38	7.71	21.20
Residual 1	4	.2247	.0562	—	—	—
Degree 2	1	.1551	.1551	6.69	10.31	34.12
Residual 2	3	.0696	.0232	—	—	—
Degree 3	1	.0654	.0654	31.14	18.51	98.49
Residual 3	2	.0042	.0021	—	—	—

Using the relationship found, and the corresponding E'_1 values, the estimated Y value was found for each corresponding X value. The fitted curve is shown in Fig. 3. Ref. 10 also gives the formula to use when it is desirable to transform the relationships back to X's.

c. Multiple Regression in a Bearing Research Problem.

One phase of a test program on the study of bearing materials was concerned with evaluation of the influence of varying factors on bearing performance. One set of factors selected was speed, load, and the viscosity of the lubricating oil. Performance was measured in the friction generated. Using a 60° segment bearing, the test was run on the standard Amsler abrasion testing machine adapted to make use of basic frictional measuring devices under varying speeds and loads. A 7 x 7 lattice plan allowed for 49 different speed-load combinations, viscosity being measured at each of these.

The theoretical functional relationship based on engineering judgment was:

$$f = b_o\ (N^{b_1})\ (p^{b_2})\ (Z^{b_3})$$

where N = speed, P = load, Z = viscosity and f = friction; the b's, the parameters dependent on test setup, to be estimated from the experimental data. The above expression is in line with Hersey's well-known ZN/P factor.

This problem illustrates the situation where a transformation is necessary to give an equation of the linear form in order to use the Least Squares criterion. Using a logarithmic transformation, the new equation was:

$$\log f = \log b_o + b_1 \log N + b_2 \log P + b_3 \log Z.$$

In order to express this equation in the more familiar standard regression form, place

$$Y = \log f,\ a = \log b_o,\ X_1 = \log N,\ X_2 = \log P \text{ and } X_3 = \log Z.$$

Then

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3$$

The corresponding normal equations are then

$$b_1\Sigma x^2{}_1 + b_2\Sigma x_1x_2 + b_3\Sigma x_1x_3 = \Sigma yx_1$$
$$b_1\Sigma x_1x_2 + b_2\Sigma x^2{}_2 + b_3\Sigma x_2x_3 = \Sigma yx_2$$
$$b_1\Sigma x_1x_3 + b_2\Sigma x_2x_3 + b_3\Sigma x^2{}_3 = \Sigma yx_3$$

TABLE XI—WORK SHEET FOR MULTIPLE REGRESSION PROBLEM c
—Correcting sums of squares and cross products to their means.

N = 49	Speed X_1 = log N	Load X_2 = log P	Viscosity X_3 = log Z	Friction Y = log f
Sum	110.523	111.091	95.125	112.643
Mean	2.256	2.267	1.941	2.299
Speed, X_1	252.590347	253.012984	212.474692	254.011640
Correction factor	249.292521	250.573686	214.561232	254.074332
Difference	3.297826	2.439298	−2.086540	−0.062692
Load, X_2		260.325115	212.630421	252.029890
Correction factor		251.861434	215.663906	255.380072
Difference		8.463681	−3.033485	−3.350182
Viscosity, X_3			186.629107	219.588080
Correction factor			184.668686	218.676844
Difference			1.960421	0.911236
Friction, Y				261.329821
Correction factor				258.947866
Difference				2.381955

This half a mirror view of above.

TABLE XII—WORKSHEET FOR MULTIPLE REGRESSION PROBLEM c
—Solution of the normal equations using the c-multiplier (Ref. 4)

3.297826	2.439298	−2.086540	1.0,0	....(1)
	8.463681	−3.033485	0,1.0	....(2)
A mirror of that above the line.		1.960421	0,0,1	....(3)

(1)(1.960....) − (3)(−2.086....) 2.1114771 − 1.5474361 = 1.9604208, 0 ....(4)
(2)(1.960....) − (3)(−3.033....) 7.3903463 = 0 , 1.9604208 ....(5)
(4)(7.390....) − (5)(−1.547....)13.2099885 = 14.4881886 ....(6)

The c-multipliers are:

$c_{11} = 1.096760$ $c_{21} = 0.229646$ $c_{31} = 1.522664$
$c_{22} = 0.313353$ $c_{32} = 0.729290$
$c_{33} = 3.2591944$

($c_{12} = c_{21}$, etc.)

The b coefficients are:

$b_1 = 1.09676\ (-0.062692) + 0.229646(-3.35018) + 1.52266\ (0.911236) = 0.54939$
$b_2 = 0.229646(-0.062692) + 0.313353(-3.35018) + 0.729290(0.911236) = -0.39963$
$b_3 = 1.52266\ (-0.062692) + 0.729290(-3.35018) + 3.25919\ (0.911236) = 0.43118$

For the analysis of variance:

$SS_{regr.} = 0.54939\ (-0.062692) + (-0.39963)(-3.35018) + (0.43118)(0.911236) = 1.697264$

Source of Variation	d.f.	SS	MS	F
Regression	3	1.697264	0.56575	37.18
Unexplained (error)	45	0.684691	0.0152154	
Total	48	2.381955		

$$R^2 = \frac{1.69726}{2.38196} = 0.71 \text{ or } 71\%$$

The standard errors are:

$s = \sqrt{0.0152154} = 0.1234$
$s_{b_2} = 0.1234\ \sqrt{0.313353} = 0.06909$
$s_{b_1} = 0.1234\ \sqrt{1.09676} = 0.1292$
$s_{b_3} = 0.1234\ \sqrt{3.259194} = 0.2229$

where as before the lower case letters indicate that the variables are measured from their mean values.

The first step in the arithmetic was to change each of the 49 sets of readings of speed, load, viscosity and friction to logarithms. The next step was to compute the required sums of squares and cross products of these 49 sets and correct them in each instance to the mean values. This is shown in Table XI of the work sheets reproduced here. These sheets, Tables XI and XII, give the entire layout of the procedure we follow in multiple regression problems.

Briefly, instead of solving the three simultaneous equations directly for the b's, a technique of matrix algebra known as the Gauss multipliers are used; these are $c_{11}, c_{12}, \ldots, c_{21}, c_{22} \ldots, c_{31}, c_{32} \ldots$, etc., reference (11), page 139. These are the elements of the inverse matrix. Using the same summations as in the left part of the normal equations, and these c's, three sets of equations may then be written with the right members being 1, 0, 0, 0, 1, 0 and 0, 0, 1, respectively. These are indicated in a compact form in Table XII of the work sheets. The solution of these yields a matrix of the c values, that is

$$\begin{matrix} c_{11} & c_{12} & c_{13} \\ c_{21} & c_{22} & c_{23} \\ c_{31} & c_{32} & c_{33} \end{matrix}$$

where $c_{21} = c_{12}$ etc.

There are definite advantages in using the c-multipliers. Frequently it happens that, for the same set of independent factors, it is desirable to examine the regressions for more than one dependent factor. Using the c's, the simultaneous equations will need to be solved only once. They greatly facilitate the computation of the standard errors of the regression coefficients. And finally, they provide a method for readily finding the new b's when a variate is omitted, reference (10), article 29.1.

Table XII of the work sheets shows the method we used in solving the normal equations. Any other method might have been used, a number of which will be found in the references.

The analysis of variance for testing the regression is also shown in Table XII. The relationship was significant, accounting for 71 percent of the variation in the log friction values.

Table XIII compares the effect of the three factors, alone and in combination with the other factors, using as our criterion, R^2, the percent of the total variation in the log frictions accounted for by the regression. Each R^2 was determined by a separate regression calculation.

Table XIII

One factor	R^2 (percent)	Two factors	R^2 (percent)
Speed	1	Speed and load	69
Load	56	Speed and visc	49
Viscosity	18	Load and visc	60

From the computations in Table XII, R^2 for the three factors was 71 percent while speed alone indicated no significant effect on friction: $R^2 = 1\%$. In combination with load, there was a considerable improvement over load alone, 69% against 56%. This illustrates a very important point, namely that the test of a factor alone is not sufficient to indicate its significant influence. There can be an accelerated effect in combination with another factor.

Viscosity in combination with speed and load has little or no additional influence on friction. It seems that there is an area of over-lapping effect of speed and viscosity, that is a tie-in between the two. This is a reasonable conclusion, since it is known that viscosity changes with speed.

Another way to measure the significance of a factor would be to test the null hypothesis that its coefficient equals zero, using its standard error. Thus, for viscosity we would have from Table XII:

$$b_3 = 0.43118, \qquad s_{b_3} = 0.2229$$

so

$$t = \frac{.43118 - 0}{.2229} = 1.93 \text{ with 45 degrees of freedom.}$$

The probability of this value of t is slightly over .05. Hence a borderline case. Also, following the procedure outlined in Step 5 of Section II, b gave an F of 3.50,—another borderline case. It so happened the percentage values had more meaning to the engineer concerned with this problem.

As was to be expected, the b_2 value (load) is negative. This would put it in the denominator in the original function, again in line with the ZN/P concept.

This and other studies indicated that the Hersey variable ZN/P works well with an exponent of around 0.5. This small value was attributed to the use of segment bearings in this test.

VI. REFERENCES

1. R. L. Anderson and T. A. Bancroft, *Statistical Theory in Research*, Chapter 13-16, McGraw-Hill Co., New York, N. Y., 1952.

2. K. A. Brownlee, *Industrial Experimentation*, Chemical Publishing Co, Inc., Brooklyn, N. Y., 1949

3. Owen L. Davies, "Statistical Methods in Research and Production, Chap. 6, Oliver and Boyd.

4. Cuthbert Daniels, "Design of Experiments for Most Precise Slope Estimation," *Industrial and Engineering Chemistry*, Vol. 43, No. 6, June 1951, page 1298.

5. B. B. Day and R. A. Fisher, "The Comparison of Variability in Populations Having Unequal Means. An Example of the Analysis of Covariance," *Annals of Eugenics*, Vol. VII, Part IV, 1937.

6. F. R. Del Priore and B. B. Day, "An application of a Simple Technique in Curve Fitting of Certain Types of Data," *The Instrument Maker*, Sept.-Oct. 1948, v. 16, #5.

7. D. B. DeLury, *Values and Integrals of the Orthonal Polynomials up to n = 26*, University of Toronto Press, 1950.

8. W. Edward Deming, *Statistical Adjustment of Data*, John Wiley and Sons, New York, 1943.

9. R. A. Fisher, "Statistical Methods for Research Workers," Chap. V, Arts 25-29.2, Chap. VI, Chap. VII, Arts 44-47, 49.1, Oliver and Boyd.

10. R. A. Fisher and F. Yates *Statistical Tables*, 3rd Edition, Oliver and Boyd.

11. C. H. Goulden, *Methods of Statistical Analysis*, 2nd Edition, Chaps. 6-10, John Wiley & Sons, New York.

12. A. Hald, *Statistical Theory with Engineering Applications*, Chap. 18, John Wiley & Sons, 1952.

13. Alexander McFarland Mood, *Introduction to the Theory of Statistics*, Chap. 13 and 14, McGraw Hill, New York, 1950.

14. G. W. Snedecor, *Statistical Methods*, 4th Edition, Chap. 6, 12, 13, 14, The Iowa State Press.

15. F. Yates, Proc. Roy. Soc. Edinburgh, 59, 184-194 Session 1938-1939.

16. Lois M. Zucker, "Evaluation of Slopes and Intercepts of Straight Lines," *Human Biology*, December 1947.

VII. ACKNOWLEDGEMENTS

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Statistical Control in Continuous Chemical Processing*

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"Continuous Process" is a term commonly used in industry. By its very nature it is employed most appropriately in modern progressive chemical industries. Since the term continuous process will be used frequently in the following discussion, a definition is presented with the hope of obtaining a basis for mutual understanding.

Defined by Kirkbride: [1]

"A system consists of the mass and energy that are confined by known boundaries. It may be either static (no movement) or dynamic (in motion). A process, on the other hand, is the method by which a change takes place within the system.

"There are two fundamental and distinct types of processes, viz., batch and continuous. In the batch process the mass is charged to the system at one time and the process is carried to completion. In the continuous process the mass is charged to the system continuously and the products are removed continuously."

Examples that may be presented of continuous processes found in the chemical industry range from the huge gas diffusion process in operation at the U. S. Government's atomic energy plant, Oak Ridge, Tennessee, or the large oil refinery operations located throughout the world, to something small and simple as the continuous distillation of tap water in the laboratory.

Continuing a step further, the concept of "unit operations" is introduced. These are operations common to different industries. In effect, Brown [2] suggests that:

"Any chemical process, on whatever scale conducted, may be resolved into a coordinate series of what may be termed "Unit Operations," as pulverizing, drying, roasting, crystallizing, filtering, distilling, or extracting. The number of these basic unit operations is not large and relatively few of them are involved in any particular process. The complexity of the treatment of these operations is real and results from the variety of conditions (variables) as to temperature, pressure, or pH under which the unit operations must be carried out in different processes, and from the limitations as to materials of construction and design of apparatus imposed by physical and chemical character of the reacting substance."

ROLE OF STATISTICAL CONTROL AND QUALITY CONCEPTS

Marketable products resulting from the processes encountered in the chemical industries are required, with few exceptions, to fall within ranges of established standards. Obviously, in order for the products to meet these standards, the in-process variables must also be controlled within limits. The in-process variable controls differ in type, complexity, and sensitivity, and these controls give varying degrees of success depending on factors too numerous to mention here.

Utilization of modern and improved control techniques has greatly improved in-process control procedures. In recent years remarkable advances have been made in instrumentation and measuring techniques; in the accuracy and sensitivity of analytical laboratory tests; and in the uses of the tool known as "statistical control."

The success of any in-process control plan still depends on the time, thought and effort applied to it. To bear this out, even with the best controls available; a control plan may not be a complete success because:

A. Valuable controls are omitted which escape recognition

B. Little effort is made to improve the control plan

C. Process improvements are not uncovered which would have been indicated through a thorough analysis of the control data.

Statistical control is a unique and exceedingly versatile control technique. It can be applied scientifically to repetitive data, and through the principles of probability and logical application, can provide a

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streamlined method for separating significant information, pointing out lines of action, and predicting the probable outcome. [3]

Statistical control, quality control, and statistical process control will be used interchangeably throughout the discussion and will be considered to have the same meaning.

A comprehension of the basic concepts of statistical control is usually necessary before applying it to data. As an adjunct to this understanding the definitions of the two components of the term quality control are presented.

The term control is defined by Shewhart, [4] by stating that:

> "A phenomenon will be said to be controlled when, through the use of past experience, we can predict, at least within limits, how the phenomenon may be expected to vary in the future. Here it is understood that prediction within limits means that we can state, at least approximately, the probability that the observed phenomenon will fall within the given limits."

In analyzing quality, Shewhart [5] points out two common aspects:

> "One of these has to do with the consideration of the quality of a thing as an objective reality independent of the existence of man. The other has to do with what we think, feel, or sense as a result of the objective reality. In other words, there is a subjective side of quality. For example, we are dealing with the subjective concept of quality when we attempt to measure goodness of a thing, for it is impossible to think of a thing as having goodness independent of some human want. In fact, this subjective concept of quality is closely tied up with the utility or value of the objective physical properties of the thing itself."

With these aspects of quality in mind, then, the physical characteristics of the product must be defined to satisfy most nearly the human wants. The human element, therefore, must be of prime consideration in the control of quality since it is part of the basic concept of quality.

HUMAN ASPECTS

Humanics cannot be stressed too strongly—not only does it decide the limits to be placed on the physical characteristics of the product, but it is an integral part of statistical control applications. The statistical analysis of repetitive measurements is of little value without initiative and imaginaton to recognize significant information, to point out lines of action, and to predict the probable outcome. Of equal importance is the part it plays in formulating and carrying out the plan. Statistical control is not purely a mechanical operation. It involves people. Human consideration is the key to the successful application of statistical control.

In a chemical plant the processes, or unit operations, are usually supervised by people with technical training. This technical training may or may not be well supported by knowledge of statistical techniques. If the supervisor has a background in statistical control he will be able to use this training to good advantage in a practical control plan. If not, he must rely on the statistician, not only to supply the statistical techniques required for the plan, but also to aid in interpreting the results of the statistical analysis derived therefrom. However, the supervisor in this case is not relieved of the responsibility for understanding the philosophy and objectives of the technique and for using his ingenuity and imagination to discover where it may be applied.

The statistician on the other hand, must be aware of the implications of the process to contribute to its control. He must be familiar with the properties of materials and limitations of equipment, the chemical mechanisms encountered, the variables which affect the process and the human characteristics involved.

The statistician and technically trained supervisor, working together with all concerned, form a most effective team to pursue the aims and objectives of statistical process control. These aims are: greater process efficiency, maximum yield of acceptable product and reduction of processing costs.

POINTS OF APPLICATION FOR STATISTICAL CONTROL

As previously stated, a process is the method by which a change takes place in a system, while a unit operation is one of the basic operations found in the system and may be common to many processes. The various conditions required in a unit operation are dictated by the process. Statistical controls should be applied to the relatively important variables in the several unit operations and statistical techniques used to study the operations collectively to obtain knowledge of their interrelations and establish over-all control of the complete process.

In a continuous chemical process of one or more unit operations the quantity of a stream entering or leaving the system during a given interval of time may be called the universe of the stream for that period. For convenience let us imagine that the universe is subdivided into individual parts whose measured characteristics will fall within a distribution pattern. We can then pick individual parts from this universe at random and expect them to conform to the princples of probablity distribution.

The statistical question is "How many parts shall we imagine exists in this universe, and how many of these parts must be removed to give a truly representative sample?" In practice the problem can be resolved by trial and error. A trial sampling frequency is selected and the samples are taken as scheduled. A statistical analysis of the data will establish the mean and the accepted variation limits. If the sampling plan does not appear to be sensitive enough to detect significant effects of the variables, the sampling frequency can be stepped up until significant information is uncovered.

To facilitate this technique the measurement of each part should be duplicated so that the buffering effect of measurement variability can be isolated from the in-process variations of the stream and the random sampling error.

Statistical control of continuous chemical processes can be carried out, therefore, through a study of the relative differences occuring between successive precise measurements. Even though the measurement is biased, but is sufficiently precise to detect relative differences, it still can be used to advantage in the continuous control analysis because the analysis is made from related variabilities. The control depends on holding the variability within defined limits and decisions are made from correlation and significance analyses of the data.

The statistical control of continuous chemical processes can:

A. Give good overall process control under routine operating conditions
B. Determine the effects of variables in the stream or on other variables
C. Give correlations from which predictions may be made
D. Give information which might lead to increased process efficiency or process simplification

A successful example of this approach appears further along in the presentation.

STEPS IN THE STATISTICAL CONTROL PLAN

With the background for the statistical control of continuous processes in mind let us proceed with the steps leading up to the execution of the final plan.

The objectives of a control plan are the reasons for its very existence. Therefore, before selecting objectives, we should consider the limitations imposed by the equipment, the process, and the people operating the process. The limitations may not appear serious but to save time and effort they should be scrutinized closely and the objectives proposed accordingly. Another consideration in the selection, of course, will be the availability of funds to carry on the project.

Having selected the objectives, a statement of the plan follows. In formulating this plan it is best that it tie in with existing controls and conform as closely as possible with the framework of present operations.

The plan must then be sold. It must be sold to responsible superiors holding the purse strings, to the foreman directly supervising the process and to the operators who are manipulating the process but who may never have heard of statistical analysis. Perhaps others must also be convinced that the plan is feasible and that it has a very practical place in the scheme of the operation. The plan must usually be presented with tact and forethought because it should have full acceptance by everyone concerned before further steps are taken. Many well founded plans have fallen by the wayside before they were well underway, through mistrust, disinterest and lack of cooperation. Teamwork is a must in the successful operation of a statistical control plan on a continuous process.

The preliminary phase, or trial period, starts with the first measurement. This period is full of uncertainties and speculation. Procedures are checked closely and the accuracy and precision of measurements verified. The methods of sampling and measuring, that were specified, must be scrutinized to detect flaws and make improvements.

As the data are being collected they are gone over very thoroughly. The statistical machinery is then set up for detecting sampling error and measuring process variability. Suitable control charts are prepared to chart in-process fluctuations on a continuous basis and a running record prepared of known changes which might affect the process. The analyses of the preliminary data should indicate inadequate sampling, if present, and a need for reorganizing either part or all of the original plan.

The trial period should also be used to acquaint everyone with the procedures that will be followed and to rehearse for the execution of the final plan. Special instructions in sampling (measuring) standards are reviewed with emphasis on taking samples which are representative of the material being measured at the time. The operations of the plan are coordinated and any discrepancies are smoothed out or eliminated so as not to plague the operations at a later date.

When the revised plan has been completed and approved the project is officially ready to get underway. A starting time is scheduled, all final arrangements made, everyone alerted, and the plan is put into operation. As significant events show up, lines of action are determined and decisions made to direct the plan toward the chosen objectives.

To summarize, the recommended steps to be taken from the inception to routine operation of a continuous process control plan are given below.

1. Investigate all aspects of the process
2. Prepare a background for the application of the statistical control technique
3. Select and state the objectives
4. Formulate the statistical process control plan
5. Organize and sell the plan
6. Progress through the preliminary phase
7. Revise the plan and tighten the organization
8. Execute the final plan
9. Strive to attain the objectives

AN EXAMPLE OF THE METHOD

Figure 1 is a model representation of Bristol's extraction process. The first extraction step reduces the volume of solution (increases the concentration of material) and produces the first spent or residual stream. The objective is to minimize the potency of material in the spent stream. As the rich stream passes through Stage B further concentration takes place and the second spent stream emerges. Similar statements apply to Stage C and Stage D; Stages A, B, and C are continuous while Stage D is a batch-type operation.

The Contribution of the Statistician

Since the overall recovery of material can be determined accurately only at the end of Stage D, and the accuracy and precision of the rich-stream analyses left something to be desired, it was necessary to measure in-process efficiency through the spent streams. The work of the statistician consists in determining the sampling for these streams, planning experiments to catalog sources of variability, analyzing sample data both graphically and arithmetically and interpreting the results of the analyses. This last step in particular must be a joint responsibility of the statistician and the process supervisor.

Outline of the Work

This example can be presented in three parts.

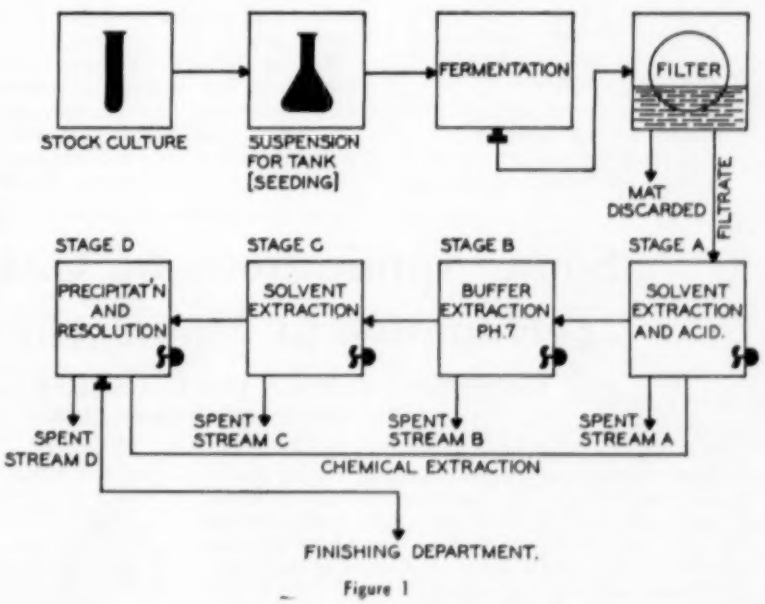

Figure 1

I. The two-week trial period
II. Routine control for 12 weeks
III. Analysis of a subsequent period of 41 weeks.

The Sampling Procedure

Before the trial period, the preliminary steps 1, 2, 3, 4 and 5 were carried out. Step 4 includes the sampling procedure which was set up as follows: Two samples to be taken of the spent stream at Stages A, B, and C during each of the three 8-hour shifts. The first sample to be taken one hour after the start of each shift and the second sample to be taken one hour prior to the end of the shift. At the final stage of the process (Stage D), one sample to be taken from each accumulated batch.

The Two-Week Trial Period

A pilot run of the experiment was made for a two-week period in order to test the plan and to allow the operators to become familiar with the operating procedures. From it we developed the following information:

1. The variability pattern was different for shifts, and days, but not for samples within shifts.
2. This statement applies within stages and across stages of the process.
3. Several samples were not taken as planned.
4. The process was not operating at several points during the two-week period.
5. Unexpected assay results occurred.
6. The net effect of this set of circumstances was to reduce the chance of definitive conclusions based on statistical analysis, but the major process characteristics were uncovered.
7. A few process changes were made, but the great value at this point was the knowledge of the control procedure acquired by operators, foremen, supervisor and statistician.

Routine Control For 12 Weeks

The sampling plan was revised whereby one sample of the spent stream at Stages A, B and C was to be taken during each of the 8-hour shifts. Also, the analytical determinations were corrected for better accuracy and precision. A 12-week period was required in order to segregate personnel effect and process effect from shift rotation. In addition to the control chart technique and the analysis of variance technique which were used during the trial period, correlation technique was used effectively in this part of the study. The following information was obtained from the statistical analyses:

1. Much of what was originally considered as possibly real, disappeared with standardization of sampling and analytical techniques.
2. Some operators performed more efficiently at certain stages of the process than other operators.
3. There were opposing relationships between some stages whereby a decrease in potency of the side stream at one stage acted to increase the potency of the side stream at the next stage. Until this opposing relationship was broken by a process change, there was no possibility of increasing the efficiency of the process at these stages and consequently increasing the overall recovery beyond a definite limit.

Analysis of a Subsequent Period of 41 Weeks

Process changes were made throughout this period and evaluated statistically. Process operating procedures were written and classroom training in chemical engineering principles was offered to all foremen and operators. A few of the detailed developments from this period were:

1. Continued amount of unassigned variability at some stages, especially Stage A. Further work should concern the fermentation process where the extraction rich stream originates.
2. Some process changes effected a subsequent stage; however, as mentioned previously, the concentration of material increases with each stage, consequently, both volume and concentration were considered in evaluating changes.
3. Further corrective action on the analytical methods made it possible to obtain a better material balance across the entire process.
4. Many of the data uncovered were not entirely understood. However, the process was brought into control and valuable information was obtained during the study. The control plan should continue and the objectives of higher process efficiency, a greater yield of acceptable product, and a reduction of processing costs should be realized.

References

1) Kirkbride, C. G., *Chemical Engineering Fundamentals*, McGraw-Hill Book Co., New York, N. Y., pp 58, 1947.
2) Brown, C. G., *Unit Operations*, John Wiley & Sons, Inc., New York, N. Y., pp 1, 1950.
3) Mueller, R. K., *Effective Management Through Probability Control*, Funk-Wagnals Company, New York, N. Y., pp 3, 1950.
4) Shewhart, W. A., *Economic Control of Quality of Manufactured Product*, D. Van Nostrand Company, New York, N. Y., pp 6, 1931.
5) Ibid, pp 53.

Some Applications of Quality Control Techniques in Motor Oil Can Filling

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This work originated when accounting reports showed extensive monthly shortages in filling stocks at our company can filling plant. The plant manager requested the operations staff group to look into the situation and determine what could be done to remedy it. All work described in this article was a joint effort of the operations group and plant personnel.

The first phase of the work consisted of investigation of the filling operations. Three filling machines were used to fill quart and gallon motor oil cans; a six-spindle one-quart, a twenty-eight spindle one-quart, and a sixteen-spindle one-gallon machine. It was found that the sampling procedure which was used at that time was totally inadequate. Two or three cans were

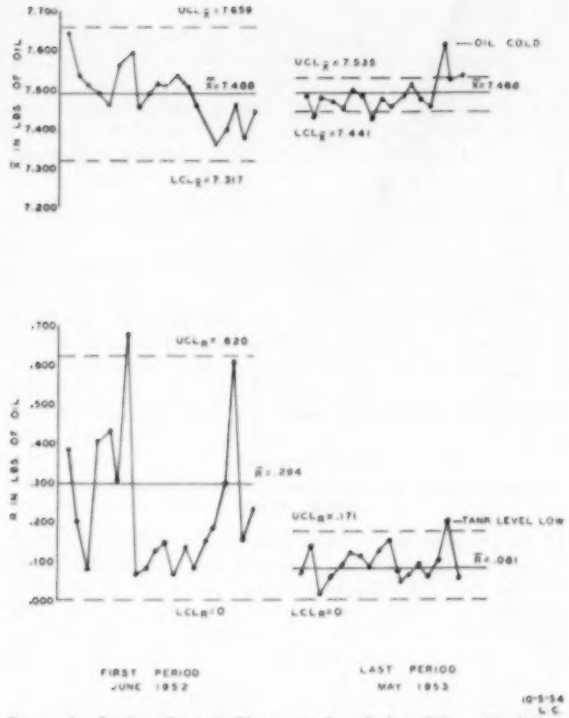


Figure 1—Quality Control Chart on One-Gallon Filling Machine.

taken from the line and weighed and the machine adjusted high or low according to the average weight. This resulted in over control; the machines were being adjusted far too frequently, and, of course, sometimes in the wrong direction. Consequently, it was decided to apply statistical quality control techniques to the filling operation.

In order to introduce this science to the operating foremen in as convincing a manner as possible, it was decided to begin by taking a large sample of several hundred filled cans from the oil filling production line. Frequency distributions were constructed from the data. This was done to illustrate that the results of the filling operation followed a recognizably normal distribution. Statistical quality control, including control chart techniques, were then explained to all the plant foremen in a series of discussions which were held weekly over a period of about three months.

This first phase of the work required considerable time, but it was felt to be worth while for two reasons. First, it demonstrated quite strikingly to the operating people that the approach used was realistic and consequently it bolstered their faith in the techniques of the program to follow. Second, it established that the type of distribution being studied was approximately normal.

The next step was the preparation and use of detailed control charts which were maintained on the filling machines. One of the first machines to which the technique was applied was the one-gallon filler. In this machine a single stream of cans is fed to 16 consecutive filling heads or spindles. Each head fills a can and ejects it to a common product stream. The order of the heads is maintained in the product stream; every 16th can comes from the same head.

Figure 1 shows an example of a control chart on the one-gallon motor oil filling machine. The sampling plan for this control chart was designed to be rational with respect to time. A sample of five cans was selected over a relatively short time period of five minutes, with approximately a one-hour interval between sampling periods. In this manner, machine drift or change between samples would be detected by use of the chart. Also, the sampling plan had to be designed to take care of the "ordering" of the filling heads in the product stream. If the individual cans were selected according to some fixed cycle, say multiples of 16, cans from a single head would appear in the sample. Samples from individual heads or limited combinations of heads would not represent the whole machine. A simple and practical way to avoid this was to select individual cans approximately one minute apart, the time interval being the time required to weigh a can before taking the next one from the line. During this interval enough cans would pass the sampler to eliminate any definite pattern. Each $\bar{X}$ plotting on Fig. 1 represents the average of five can weights obtained in this manner.

The control chart would thus be expected to show wider limits than control charts for individual heads provided there is a difference between heads. The method used for isolating and measuring the difference between heads will be discussed later on in the article. Detection and elimination of important causes of variation resulted in the narrower control limits shown as of May, 1953.

The lower portion of the chart shows the range, R, of each sample of five cans. The wide control limits and scattered range data indicate considerable variability during this first period, June, 1952.

The much narrower control limits as of May, 1953, show the progress which the plant made in keeping filling operations under better control. This reduction was achieved through systematic elimination of causes of variation.

The May, 1953, group was selected to show the improved control on the process average and range, and to illustrate a "run" during this period. A "run" constitutes a means for interpreting the chart in addition to the case where a value falls outside the control limits. Here, 12 out of 14 averages fall on the same side of the central line, $\bar{X}$. Since this event would very seldom

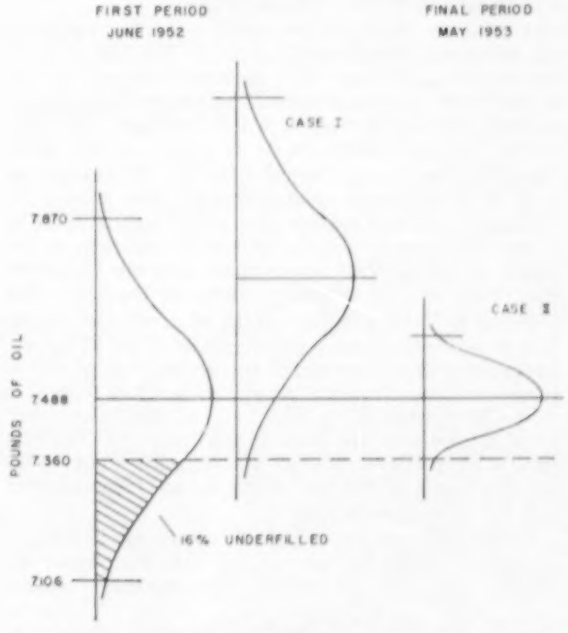


Figure 2—Distribution of Individual Can Weights on One-Gallon Filling Machine.

occur by chance, one concludes that a new factor has caused a deviation from expected results, and effort spent seeking it is justified.

Normally, when the plottings show lack of control, assignable causes are identified and eliminated. The control limits and central line are then recomputed. If this were done, the chart would show that the averages had shifted down. In this particular case we proceeded differently. The central line was left at the previously established target filling level, and the control limits were then added. When the plottings were made, they indicated a "run," showing that the target value was not being maintained. The probability is very small that such a run would occur by chance alone if the true average were at the central line. Consequently, we concluded that the average had shifted down and took action to bring it back up to the target level. In this case the run is also accompanied by two plottings which are out of control low, and which constitute a strong indication by themselves.

When the total picture of before and after is thus viewed, the plant's progress becomes obvious. Reducing the variability results in an economy in the following manner.

Figure 2 shows normal distribution curves for individual can weights in three cases. The first case represents the first period, June, 1952, previously referred to. It will be observed that 16 percent of the cans could be expected to be underfilled. The large percentage of underfilled cans could be remedied in either of two ways. First, the variation could be left alone (Case I) and the average overfill simply increased enough to fill essentially all cans to the one-gallon level. This would have required raising the average fill by 0.25 lbs./gal. and would have cost approximately $25,000 per year for additional oil fill on this one machine. The other approach (Case II) was the one taken—namely, to leave the average fixed and attempt to reduce the variation. This approach was quite successful. In fact, if a good state of statistical control can be achieved, the average can be reduced and still give an expectation of only 13 cans in 10,000 to be underfilled.

In order to facilitate the analysis of the variation, two additional techniques were used. The first of these was the group control chart as first developed by the British* and sometimes known as the multiple spindle analysis. For a description of this technique, see *Statistical Quality Control*, by E. L. Grant, p. 169. Also, "Applying the Group Control Chart for $\bar{X}$ and R," by D. F. Boyd, *Industrial Quality Control*, Nov. 1950, p. 22.

Figure 3 shows a portion of a group control chart as it was first used to analyze sources of variation in the filling operation. Only the average data are discussed, since they were of primary interest at the time. The ordinate is $\bar{X}$, or average weight of a rational sample of five cans taken from a given spindle of the 28 spindle one-quart filling machine. The abcissa is subgroup or sample number. Rational samples were taken from each of the 28 spindles of the machine, five cans being taken from spindle one, five from spindle two, etc. The idea here is to compare spindles to determine whether the spindles are significantly different, and consequently, a factor causing variation.

Under ordinary circumstances, where the number of spindles is small, say four or six, only the largest and smallest averages are plotted. For example, a sample

*"A First Guide to Quality Control for Engineers," pp. 24-28, Ministry of Supply Advisory Service on Quality Control, Berkley Court, Glentworth Street, London NW 1, England.

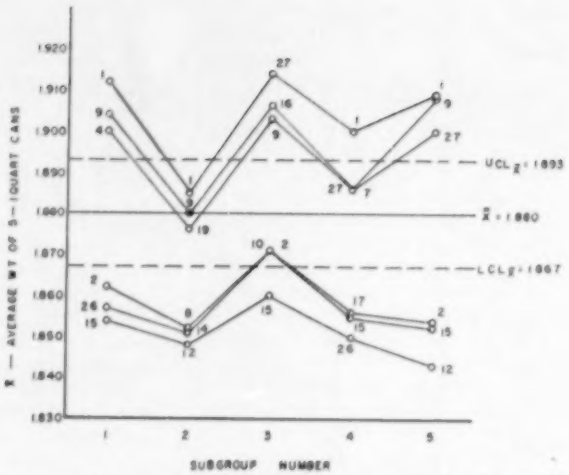


Figure 3—Group Control Chart (Sometimes Called a Multiple-Spindle Analysis.)

of five cans is taken from each of the spindles, the results recorded, and the averages and ranges calculated. In our case for the first subgroup from all spindles, spindle one came out with the largest average, and spindle 15 the smallest. The average for spindles one and 15 are thus plotted on the control chart and a small "1" and "15" added by each point. This procedure is repeated for each subgroup. Now if, for example, No. 1 turns out to be the highest too frequently, (and it did) we can conclude that it actually averages higher than the others.

In our special case, since there were a relatively large number of spindles, the three highest and three lowest averages were recorded. This was done simply to sort out the offending spindles faster. For example, the chart shows:

Spindle Number	Number Times in First Three	
1	4	Highest
9	4	
27	3	
2	3	Lowest
15	4	
26	2	
12	2	

In this manner the most radical spindles were quickly sorted out and corrected. Before readjusting the spindles it was first necessary to measure their absolute level rather accurately, to determine how far to move them. This was done using an ordinary control chart technique on each spindle.

Figure 3 also includes control limits which were obtained from the range data on each of the samples of five cans on the 28 separate spindles. The range on spindle samples of five is a measure of the variation within spindles; averaging 28 spindles for five subgroups (140 range values) gives us a pretty good measure of the within-spindle variation. When the resulting control limits are drawn around the grand average $\bar{X}$, they show the area in which the averages could be expected to fall if no spindle-to-spindle differences existed. Obviously, a good many of the spindle numbers in the portion of the chart shown indicate significant spindle differences and justify action. However, first things first, and it seemed best to correct those "repeaters" which were the furthest out of control.

Analysis of variance* was another technique which was felt to be helpful in analyzing the causes of variation in the several filling machines. Before this powerful statistical tool could be applied, it was necessary to determine which factors should be included in the analysis. The factors were suggested largely by the operating people whose experience was thus utilized in their selection.

Table I shows an example of variance analysis on the one-quart filling machine. Two main effects, spindles and days, were tested, the days' effect coming out insignificant. The spindles' effect was significant, being in agreement with the multiple-spindle control chart findings. The variance analysis showed one first-order interaction, spindle-days, to be significant. This means that the spindles are different on different days; that is, the spindles are significantly different, but probably wander about from day to day. This was an interesting and important finding inasmuch as it had to do with some sort of drift in the apparatus. Referring back to the multiple-spindle analysis, Fig. 3, we see that the interaction is indicated by this technique also. For example, comparing subgroup two to subgroup one, we see a general "drift" of the whole machine at the time this subgroup was taken. The significance of this interaction factor then, justifies attempts to find its cause.

One other interesting aspect of the interaction idea is brought out in the variance analysis table. The main effects are, of course, compared against the interaction term for significance, since interaction is significant here. The presence of the large interaction term in the main effect "days" may be masking this effect such that it really is significant, but not large enough to stand out. A further pursuance of this technique should be done in this case—namely, breaking the experiment down into individual experiments—for example, spindles, and then testing days on given spindles.

*For a more complete description of this technique see K. A. Brownlee: "Industrial Experimentation," p. 87, Chemical Publishing Co., 212 Fifth Avenue, New York, N. Y.

TABLE I—Analysis of Variance Twenty-Eight-Spindle, One-Quart Filling Machine

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio
Spindles	26.971	27	999	1.73*
Days	1.854	2	927	1.6 **
Spindles x Days	31.228	54	578	6.4 ***
Error	30.285	336	90.1	
Total	90.338	419		

*Significant at 0.05 probability level.
**Not significant.
***Significant at 0.001 probability level.

This technique is also discussed in detail by K. A. Brownlee in the reference given. Since this is essentially what was done with the multiple-spindle analysis using individual control charts, it is not included as a variance analysis technique in the article.

The multiple-spindle analysis, variance analysis, and control chart techniques, all contributed toward bringing the operation into a state of "control" and yielded tools to keep it there. Large components, or causes of variation, were found by use of the control chart. Other more subtle causes were found by the more refined tools discussed. These causes were eliminated or reduced by engineering approaches.

Other benefits to the filling plant as a result of the cooperative work undertaken have been:

1. Introduction of statistical quality control by these and other examples
2. Applications of the methods to other problems
3. Statistical concept of specifications and the setting of realistic tolerances
4. Prompted search for underground leaks, resulting in their location and elimination.

Planning and Operating a Receiving Inspection Department*

ARCHIE R. JACKSON**

Allen B. Wrisley Company, Chicago, Illinois

No single phase of quality control has as wide spread applications or affects as many departments and operations as the receiving inspection function. At the upper end of an industry scale, the material being received would be covered by detailed blue-prints, specifications, and association agreements which are vigorously enforced by all parties. At the lower end of the scale, they deal in strictly commercial materials where price and delivery are the main considerations and it is just understood that you take what you get. Somewhere between these two extremes lies the type of material almost everybody uses. In spite of the necessity for a receiving inspection operation, many industries have not gotten into the act. This may be due to uncertainty on how to start. What sampling plan to use? How to administer it? Maybe we can get along without it. Most quality control and inspection people have been introduced to various types of sampling tables, their operating characteristic curves, and even classification of defects. However, the main difficulty to me appears to be in just getting started; so this article discusses "Planning and Operating a Receiving Inspection Department."

*This article was presented on the Program of the Tenth Annual Rochester Quality Control Clinic, Feb. 16, 1954.

**Mr. Jackson is now with the Mitchell Manufacturing Company, Chicago, Illinois.

NATURE OF THE BUSINESS

To gain some idea of the importance of this receiving inspection function, we should consider the nature of business to which it is related. Ours is soaps and cosmetics with a very wide variety of products. We average about 2,500 active products which are in a constant state of change. It is the very nature of the business that product, packaging, or merchandising seldom is the same from year to year or

even from season to season. Some of the items carry the Wrisley label but item-wise we make more under customer labels, which we call "private brand." They are made for the leading department stores, grocery chains, drug chains, jobbers, perfume houses, industrial users, laundries, wagon and truck routes, etc. Each one has different problems which are reflected in their products' specifications and hence in the receiving inspection operation. In general, the products consist of: milled toilet soap, liquid and soft soaps, soap flakes both pure and filled, milled soap flakes, tower blown soap granules, ground soap granules, hand cleaners, wall cleaners, bath salts, bubble bath, creams, lotions, colognes, hair dressings, shampoos, gift sets, and glycerine. From this variety of products and customers, some idea of the magnitude of the problem presented to control the quality of the incoming components may be seen.

WE HAVE PROBLEMS

Prior to the setting up of a quality control department with a receiving inspection operation, our situation was much the same as any organization which has attempted to get along without formally checking each lot as it is received and recording its findings. As material was received, it was checked in for quantity; samples given to sales, purchasing, and development for their comments and decisions; and placed in the warehouse. As it was requisitioned out for use we depended on the factory user of the material or packaging supplies to check the quality and performance. This might be within a few days after it was received or a matter of months. When things were found wrong, operations came to a jarring halt; but not always before there had been a lot of lost time and scrap. Under such conditions it was inevitable that many things went through unnoticed or not reported, to be picked up later by the customer or sales personnel. Reporting such difficulties back to the sources of supply, weeks or months after the receipt of the material, did not always promote the best of vendor-user relationships. Difficulties experienced in the use of the material and the resultant lost time in the plant were worrisome. The time lost in failure to meet schedules and being forced to sort the acceptable product from the unacceptable were heavy cost items. On top of all this, we had no way of evaluating or checking the level of the quality of the materials coming into the plant.

THE ALLEN B. WRISLEY CO.

RECEIVING INSPECTION PROCEDURE SHEET Q. C. 10

Commodity Number 337 - 12 oz.	Supplier's Name "M" Company - Bottles "S" Company - Screening
Commodity Name May Fair Hand Lotion Bottle	Supplier's Address Chicago "M" Company
Purchase Order No. 17905, 15910, 03181	Approved Suppliers "S" Company

FACTORY Q. C.

ABJ	ABJ	10-26-48
Instructions By	Authorized By	Effective On

CHARACTERISTIC	% INSPECTION	CHECK BY
Overflow capacity - 12 oz. & 4#	4 from each mold No.	Laboratory
Thread Diameter - 2400	Sampling plan	Gage & 24.8 cap
Open finish	"	Gage
Neck Height - tall	"	Gage & 24.8 cap
Glass Distribution	"	Visual
Glass color - clear	"	Visual
Surface Imperfection	"	Visual
Gross weight	"	Scales
Bottle Formation and neck contour	"	Visual & 24.8 cap
Screening - Blue and Gold (check with furnished samples.)	"	Control samples

Commodity Must Be Tested as Indicated:	Special Instructions:
On original order make complete check of each mold number	Packed in reuse cases - 1 dozen with partitions

Manufacturing Difficulties Experienced Are	Customer's Complaints Reported:
	Printing not clean and distinct.

Figure 1

PLANNING THE PHYSICAL SET-UP

From previous experiences in setting up receiving inspections, I knew that much preparation work must be done before it could become a going operation. Planning must be started on different phases to meet a cordinated time schedule and not hold up its progress. The actual receiving function was concentrated in two spots: one to handle truck and tank car shipments of basic fats and chemicals; the other to receive the balance of the wide variety of materials. The physical arrangement of our plant lent itself well to this operation as there were definite control points through which the material had to go before the receiving manifests could be made up for admittance to stock rooms and warehouses. Adjacent to this receiving area, we located our receiving inspection office and testing area. Space was set aside in which to hold temporarily the shipments awaiting sampling and clearance. While these areas were being prepared, we started work on our sampling inspection plan and receiving procedures.

GATHERING PRELIMINARY INFORMATION

Only a very small portion of the items to be inspected had any specifications beyond price, delivery, and a general agreement to be commercially acceptable. The task ahead appeared to be long and detailed. We listed 2,500 different basic commodity numbers. Each of these commodity numbers in turn had as many as 20 point or sub-numbers denoting an item used in that commodity. For instance, it might be a #751 cologne which would use a 751.1 bottle, 751.2 cap, 751.3 label, 751.5 ribbon, 751.10 case, etc. This ruled out an initial ful' and completely detailed inspection procedure for every commodity and point number. The classification of inspection

characteristics into varying degrees of seriousness such as: critical, major, minor, and incidental would multiply the problems again. The use of different quality levels for certain items and/or characteristics would require several inspection plans which would in turn complicate the inspection work. No previous knowledge of vendor's history or process averages was available as a guide. Each item as received might be a one time proposition or continue for years. The selected plan must encompass all these problems and be fair to both our suppliers and to the company.

We gathered together all the information we had available from purchasing, sales, product development, laboratories, and factory. This was grouped as related to general classes of materials or products without trying to tie it down to specific items. This served as the frame-work for general inspection characteristics. We applied this general information to the specific commodity and point numbers. Hence a general weight specification was changed to so many pounds or ounces. Color became red per sample, proof, or color book. Size would now be a definite dimension, say $6\frac{3}{4} \pm 1/64$ inches. Grain of paper to run length of cut sheet. Caps to fit a specific bottle, gage, etc. This information was all recorded on a receiving inspection procedure sheet which covered all characteristics to be checked and recorded. (Figure 1.)

Each commodity and point number has an individual folder in which all records relative to it are placed. This includes the inspection procedure sheet, purchase orders, correspondence, copies of all completed receiving inspection reports, supplementary tests of laboratories, re-work orders, and quality control floor check reports. Testing methods to be used, manner of storage, experience of plant with item, trouble due to it as reflected in customers' complaints, and in general our combined experience with this particular item is all shown. This is added to as time, experience, and conditions warrant.

WE LOOK AT PRESENT INCOMING MATERIAL

We had no previous knowledge as to:

1. The size of incoming lots.
2. Past history of suppliers.
3. Expected fraction defective or nature of defects.

As a trial plan, we decided to use a true sequential which in my past experience had been used very successfully in the aircraft industry. It was based on an arbitrary acceptable quality level of two percent and an unacceptable quality level of ten percent. The risk factors were set for acceptance 95 percent of the time for the acceptable quality of two percent (rejection five percent of the time); and acceptance of the ten percent undesirable quality only one percent of the time. Also, since there is no change in sample size regardless of lot size, it would be a plan easy to administer in this exploratory stage. Using this selected plan, we started collecting data. This we did by inspecting every shipment received for three consecutive months. The original procedure of accepting all lots as received was still carried on. We kept all of the results of our inspections to ourselves during this test period. The average fraction defective during these three months varied between 25 percent and 32 percent for the characteristics listed. We had a conference with the management, purchasing, and factory where we thoroughly discussed our findings. It was decided that our principal sources of supply would be notified that starting with October of 1947, all incoming material would go through a receiving inspection operation. For a 60 day trial period, no lots would be rejected, sorted, or repaired without a mutual agreement between the supplier and the purchaser. Any action taken on these rejectable lots had to be in the best interests of all parties. The rehearsal was over and now we were ready for the real show.

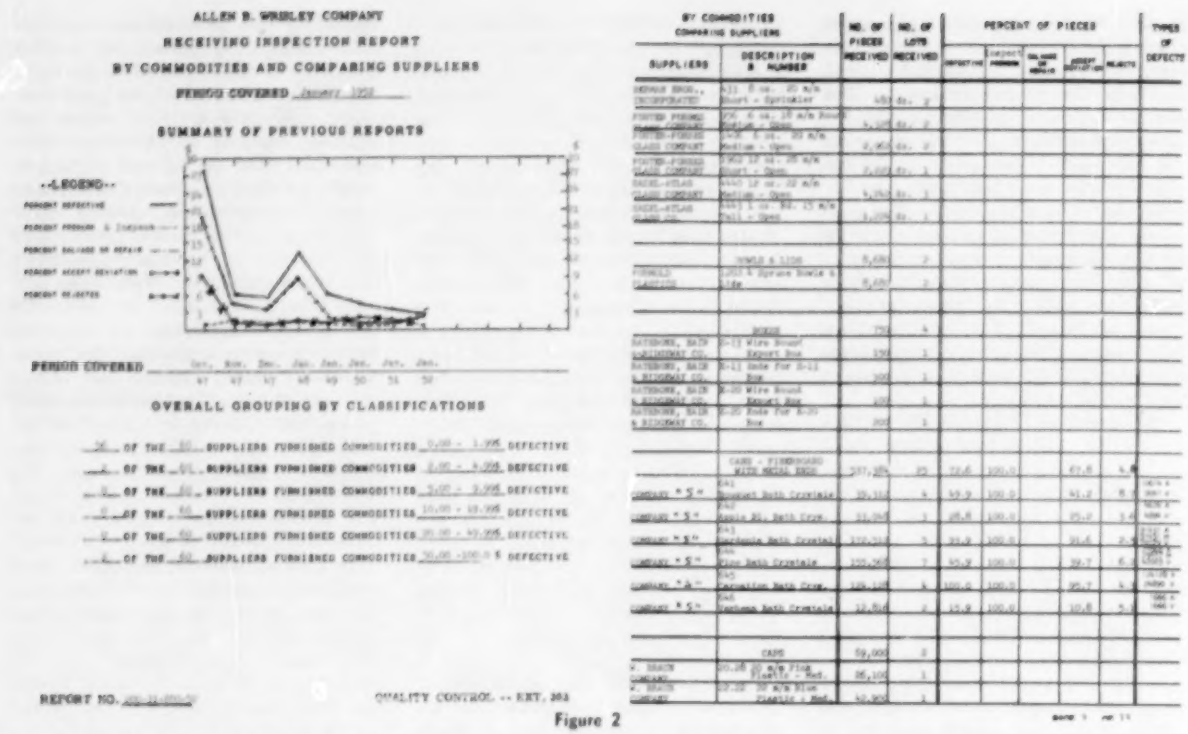
SLECTION OF SAMPLING PLAN

From this preliminary inspection, it was noted that about 75 percent of all the lots were accepted as being less than two percent defective; and about 15 percent of the lots were rejected as being ten to 100 percent defective. This meant that our materials as received were either very good or very bad and we only had ten percent of the lots in the "undecided zone" or two to ten percent defective. Therefore, a plan that would make quick decisions on very good or very bad material seemed to be indicated. A true sequential plan does just that, so we adopted for regular use our trial plan which was based on an acceptable quality level of two percent, and an unacceptable quality level of ten percent, a five percent risk of rejecting the acceptable quality and a one percent risk of accepting the unacceptable quality. Knowledge of suppliers or process averages is not required to set up a sequential plan. But its performance will depend very much on realistic choices of the four basic constants just mentioned. Changes in the selected acceptable and unacceptable percentages, and/or their related risks will have a direct effect on amount of sampling required and the sequence of acceptance and rejection numbers to be used. To attempt to discriminate by sampling between say, one percent and three percent quality means a larger amount of sampling and hence more inspection. Taking smaller risks has the same effect. The reverse also holds true going the other way. No classification of defects as to varying degrees of seriousness was attempted in order to keep the operation easy to administer. Also, since our responsibility covered the use of the item, such classifications would add to the detail and mean additional sampling plans. Any lot that failed to pass the plan would be reviewed and dispositioned within 24 hours.

We anticipated that while many lots would not be accepted by our sampling plan, since they would not involve an out-right rejection, we would have ample opportunity to discuss them and our specific needs with our suppliers. As it worked out, not a single unhappy incident took place. We all realized we could not continue to live with material which averaged 25 percent defective. However, it should be kept in mind that this *was* an average percent defective, made up mostly of very large lots which were almost 100 percent defective for the characteristics listed.

INTRODUCTION OF PLAN TO OUR SUPPLIERS

In October of 1947 after our first full month of operation we prepared two reports which covered in full detail the results of our inspection. One of these reports was compiled by commodity and the other by supplier. We also prepared for distribution to our suppliers a write-up covering our "Sequential Plan," its values, mathematical computations and justifications, and use of either a "graph" or "table" as a means of explaining and instructing the inspectors. (Armed with this write-up a plan may be developed for any given acceptable and unacceptable qualities.) Our purchasing department forwarded this material to our suppliers. We now had a fairly good



ALLEN B. WRISLEY COMPANY

RECEIVING INSPECTION REPORT

BY COMMODITIES AND COMPARING SUPPLIERS

PERIOD COVERED January 1950

SUMMARY OF PREVIOUS REPORTS

--LEGEND--

PERIOD COVERED Oct. Nov. Dec. Jan. Feb. Mar. Apr. May.
47 47 47 48 49 50 51 52

OVERALL GROUPING BY CLASSIFICATIONS

26 OF THE 50 SUPPLIERS FURNISHED COMMODITIES 0.00 - 1.99% DEFECTIVE

2 OF THE 50 SUPPLIERS FURNISHED COMMODITIES 2.00 - 4.99% DEFECTIVE

0 OF THE 50 SUPPLIERS FURNISHED COMMODITIES 5.00 - 9.99% DEFECTIVE

0 OF THE 50 SUPPLIERS FURNISHED COMMODITIES 10.00 - 19.99% DEFECTIVE

0 OF THE 50 SUPPLIERS FURNISHED COMMODITIES 20.00 - 49.99% DEFECTIVE

2 OF THE 50 SUPPLIERS FURNISHED COMMODITIES 50.00 -100.0 % DEFECTIVE

REPORT NO. [illegible] QUALITY CONTROL -- EXT. 203

BY COMMODITIES COMPARING SUPPLIERS

SUPPLIERS	DESCRIPTION & NUMBER	NO. OF PIECES RECEIVED	NO. OF LOTS RECEIVED	PERCENT OF PIECES DEFECTIVE	REJECT PREWORK	SALVAGE OR REPAIR	ACCEPT DEVIATION	REJECTS	TYPES OF DEFECTS
[illegible]	[illegible]	[illegible]	[illegible]						

2. A random sample is selected and checked for all the characteristics on the receiving inspection procedure sheet.

3. If it is accepted by the plan, the receiving report is stamped "Accepted," signed and dated. The receiving inspection report made out for each shipment shows that the sample contained no defects or the amount was within the allowable percentage. This report is then placed in the parts file.

4. This receiving report admits the goods to storage and releases it on the production control and warehouse records as available for use. No goods are placed in storage without this release and the permanent book tissue copies of the receiving reports are checked each morning to be sure everything has been inspected.

5. Each shipment as received is shown on a numbered daily record for quick reference as to what happened to the lot and where it was stored.

6. If the shipment is rejected by the plan, the results of that inspection are shown by characteristics and by piece on the receiving inspection report. (Figure 3.) The paper work with proper and representative samples of the defective material are taken directly to the purchasing agent. After looking it over, he may sign the report to accept the deviation or reject the material. Rather than return the shipment, he may contact the supplier and explain the difficulty or ask him to send somebody in to look the material over. The decision may be to sort out the bad material or repair or salvage it in some manner. On work of this kind, we usually secure a job number against which we charge the labor with the supplier's prior consent. Whatever the decision, it is signed for on the receiving inspection report. If purchasing does not want to take the responsibility alone, we will secure the affected sales department's approval for the action also. If it involves extra hardships on the factory, they sign for it. An additional manner to handle shipments has been added in the past year. It is "Accepted Pending Inspection in the Plant" to cover items which can be handled most economically in this manner. In every case, the report constitutes the *written approval* of the conditions we have called to their attention. Since quality control is not fully relieved of responsibility by these signatures, action taken which does not appear proper can secure full approval by getting top management to sign for the material. Shipments are not returned to the supplier unless that is the best way to handle it and the action will not stop or hold up the production schedules. Again, this is discussed with the supplier before the shipment is returned.

Referring specifically to the results of inspecting a shipment of #337 bottles (Fig. 3), the following comments are offered. The 54 Pcs. means that a random sample of that size was taken. If it had been a color or chemical, the industry recommended sample would have been inserted and so marked. The "overflow capacity" by the laboratory square signifies the work requested of the laboratory. The Rec. Insp. Area shows where the inspection was performed. The "Other" square would be filled in if bottles were tried out on a filler; otherwise left blank. The information in Section I covers the detailed inspection of the sample by individual characteristics. Section II shows results by pieces, with 46 of the 54 nonconforming, or 85.2 percent defective. Our estimate of those defects which could be accepted with deviation was 14.8 percent. Both of these figures were very close to those found when the bottles were 100 per cent inspected with results of 87.0 percent and 13.0 percent, respectively. The rest of the figures are self-explanatory.

THE RESULTS ARE GOOD

After several years of experience in receiving inspection, we have found that our suppliers are also happy over the arrangement. Whether or not they have a quality control organization, they report that knowing we inspect their material keeps them on their toes and provides them with a measure as to the kind of job they are doing. If we accept their shipments they know they are turning out a good product. Sorting jobs and rejections are discussed fully before the work

THE ALLEN B. WRISLEY COMPANY
RECEIVING INSPECTION REPORT

Commodity Number: #337 - 1407 BOTTLE
Commodity Name: MAYFAIR HAND LOTION
Supplier's Name: S" COMPANY
Purchase Order No.: 05146
Receiving Report No.: 12529
Date Received: 8/10/51

RESULTS OF INSPECTION

Type of Inspection Used: 54 Pcs. | Statistical Sampling | Overflow Capacity | Laboratory | Rec. Insp. Area | Bench | Bottle Capper | Other

I. RESULTS BY INDIVIDUAL CHARACTERISTICS (Detail)

Characteristic	In First Sample: No. of Pcs. Inspected	No. of Defectives	Percent Defective	In Other Samples: No. of Pcs. Inspected	No. of Defectives	Percent Defective
Printing Smudged and Filled	54	27	50.0	5		
Blue Color Not Evenly Distributed	54	19	35.1			
Blue Printing Not Registered Properly	54	10	18.5			
Two Different Kinds of Gold	54	7	12.9			
Light Coverage of Gold	54	4	7.4			

II. RESULTS BY PIECES (One or more defective characteristics)

Number of Pieces in Shipment: 30144
Number of Pieces Inspected: 54
Number of Pieces Accepted: 3912
Number of Pieces Rejected: 26232

IN FIRST SAMPLE: No. of Pcs. Inspected	No. of Defectives	Percent Defective	Percent Premium	Percent Salv. or Rep.	Percent Acc'pt. Dev.	Percent Rejected	IN OTHER SAMPLES: No. of Pcs. Inspected	No. of Defectives	Percent Defect.
54	46	85.2	100.0		14.8	85.2			

REQUEST FOR DISPOSITION OF REJECTED LOT

Disposition Authority is Requested for the Following:

Group	Description of Rejected Material	Group	Description of Rejected Material
A	ENTIRE LOT TO BE SORTED AND COMPARED WITH APPROVED VISUAL SAMPLES. CHARGE LABOR ON BOTTLES BACK TO JOB NUMBER J 52-223-111.1 (30144 PCS.	B	REJECT ~~SELL~~ RETURN ALL UNSATISFACTORY BOTTLES TO SUPPLIER - (26232 PCS.)
		D	ACCEPT WITH DEVIATIONS THE (SAMPLE BOTTLES - (3912 PCS.)

Group Requiring Disposition	Number of Pieces	Method of Disposition	Requested By	Date	Approved By	Date
A	30144	100.0% Percent of Inspection	W. GUZY	8/10	W. R. Lang	8/10/51
D	3912	Salvage or Repair; Accept Deviation 13.0%	W. GUZY	8/10		
B	26232	Rejected 87.0%	W. GUZY	8/10		

Handled per Disposition on 8/15/51 By J.P. Dep't. COSMETICS

Form 50-46

( ) Rejected
( ) Accepted pending Inspection in Plant
( ) Accepted
Receiver was stamped ( ) Not stamped
(✓) Hold for Disposition

V. Blair

WAREHOUSE Copy

Figure 3

starts or the goods are returned, which saves money in shipping charges.

It has been our observation that the quality improved greatly as our suppliers knew we were inspecting their shipments. In fact it dropped from 27.5 percent the first month to less than ten percent in three months and has improved steadily since then. Once they knew what we wanted, they made the improvements themselves and it was not necessary to change suppliers except in cases of incurables.

Since we have quality control all through the operations, we have opportunities to see just how efficient our receiving inspection really operates. For a whole year, we only found three cases where our plan admitted material which it should have caught. But even this was less than our calculated risk as it was set up to accept one percent of shipments due to chance alone that were really ten percent defective. Now, when material has been accepted, we feel safe in scheduling production involving its use.

Just what does it cost to handle such a set up? One full time man now handles it all, even to following through and securing most of the approvals for the receiving inspection reports where necessary. The making up of the monthly reports is an office function which requires six hours of tabulation and an additional six hours of typing and compiling of the report. The securing, posting and issuing of the fats and oils report involves about 20 hours of work a month.

But things were not always so simple and organized as they are at present. Just as in all quality control projects, a great deal of time was spent originally in planning, conferences, and cooperative effort. Six weeks were required by one man in selecting the characteristics to be checked. During this time, he worked with every affected department head in recording those characteristics which they knew from past experience should be checked and had given them trouble. Of course, in these early stages even those specifications were rather general, but as time went on they became more specific and detailed. At the present time they embody the combined experience of the entire organization with that specific part during the past six years.

We also owe a great debt to our purchasing department which has worked unceasingly with our suppliers, as the go-between man, in making our needs known to our sources of supply. Without the cooperation of the purchasing department it is almost impossible to operate a sound and smooth-running receiving and inspection deparment.

All in all, it is a fairly compact set-up, designed and built for our type of operation: details where they are required; knowledge of materials and their intended uses; simplification when it will do no harm.

Local Section News

"... BUT NOT FORGOTTEN"

DALLAS -FORT WORTH Eighty-four persons attended the Third Annual Dinner Meeting of the Dallas-Fort Worth Section, at the Fort Worth International Airport, on June 16. L. L. Turner, Assistant to Manager, Convair-Fort Worth Division, guest speaker, gave a sprightly after-dinner address to this well attended meeting.

BIRMINGHAM At a meeting on June 13 of outgoing and incoming officers, progress was made in the development of a program to revitalize the Birmingham Section. An intensive mail campaign and personal visits, under the Chairmanship of Neil Zimmerman, will be conducted during the next few months. It is planned to contact approximately 300 organizations.

INDIANAPOLIS Lafayette Subsection On June 15 the Lafayette Subsection held its final 1954-55 meeting at the Biology Annex of Purdue University. Dr. Irving Burr, Professor of Mathematics, Purdue University, presented a "Summary of the 1955 Annual Convention." Primarily his subject covered the many important conference papers.

KANSAS CITY On June 8 the Kansas City Section held a dinner meeting at the Blue Hills Restaurant. Members Hugh Springer and H. C. Heyde gave reports to the section on their trip to the Annual Convention. Hugh Springer, newly elected Section Chairman, announced the appointments of the various committee chairmen. After all business was transacted, the meeting adjourned for the summer.

MICHIGAN The last meeting of the current season was a fitting climax to a very successful year. It was a question and answer affair by a panel composed of several Michigan Section experts. They answered all queries fired at them by a good crowd that assembled for this last session.

NEW HAVEN On June 8, the Executive Committee met at the home of the newly elected chairman, Bob Callahan, to formulate plans for the coming season. Committee chairmen presented their programs and ideas to further promote the Section's objectives and insure a successful season. These sessions will continue throughout the summer.

This Section has also distributed a questionnaire to all the membership soliciting ideas for a better program this coming season. Several offered very good ideas for the new educational program and the Executive Committee will be guided by these suggestions.

SEATTLE Dr. Francis J. Pilgrim, Assistant Chief, Acceptance Division, Quartermaster Food and Container Institute for the Armed Forces, Chicago, presented "Measurement of Preference and Flavor in Food Acceptance Research and Quality Control" on June 14 for the year-end meeting of the Seattle Section. This meeting was planned as a "Ladies' Night" and 109 members, guests and their ladies were present to enjoy Dr. Pilgrim's talk following cocktails and Smorgasbord.

STATE UNIVERSITY OF IOWA The June 3 meeting of the State University of Iowa Section was in Iowa City. H. R. Harrison, Collins Radio, Cedar Rapids; Lloyd Knowler, State University of Iowa; E. W. Langill, John Deere Ottumwa Works; and Fred Halton, were the featured speakers. Those attending the meeting obtained both basic and advanced quality control techniques as presented by this group of excellent speakers.

TENNESSEE
Memphis Subsection The June 28 meeting of the Memphis Subsection was held in the Community Service Room of the Leader Federal Savings & Loan Building. Mr. Charles Latimer, Director of Research Development at Nickey Brothers Lumber Co., spoke on "Highlights of the Ninth Annual American Society for Quality Control Convention." An additional subject, "Quality Level Certification" supplemented with illustrated slides furnished by the Ford Motor Co., was also given.

WINDSOR June 20 saw the completion of the 30 hour training course on "Statistics Used in Quality Control." Mr. M. D. Nicholson, Timken Roller Bearing Co., St. Thomas; Mr. Calvin Kirchen, Engineering Research, Ford Motor, Dearborn; and Mr. D. J. Malott, Essex Wire Corp., Ltd., acted as instructors.

"... CAST THEIR SHADOWS BEFORE"

INDIANAPOLIS
Lafayette Subsection A Kick-off dinner meeting is being planned for the month of September. Mr. L. B. Bornhauser, Indianapolis Chrysler Plant Manager will be the featured speaker.

KANSAS CITY The first meeting of the fall season of the Kansas City section will be Sept. 14 at 6 p.m. The dinner meeting will be held at the Blue Hills Restaurant. Hugh Springer, Chairman, has dedicated this meeting to membership development with a request to each member to bring a guest as a potential new member.

SAN BERNARDINO Mr. Dale Lobsinger, United Air Lines, Denver, Colo., has been scheduled as the speaker at the first meeting of the 1955-56 season of the San Bernardino Section to be held on Sept. 1. Mr. Lobsinger will discuss the use of SQC methods in management controls.

ST. LOUIS The next meeting of the St. Louis Section will be held on Friday, Sept. 16, beginning at 8 pm in the Chouteau House at St. Louis University. A social gathering and dinner will precede the meeting.

WESTERN MASSACHUSETTS The September meeting of the Western Massachusetts Section is presently in the planning stage. Individual announcements will go out to all membership as soon as the date is set.

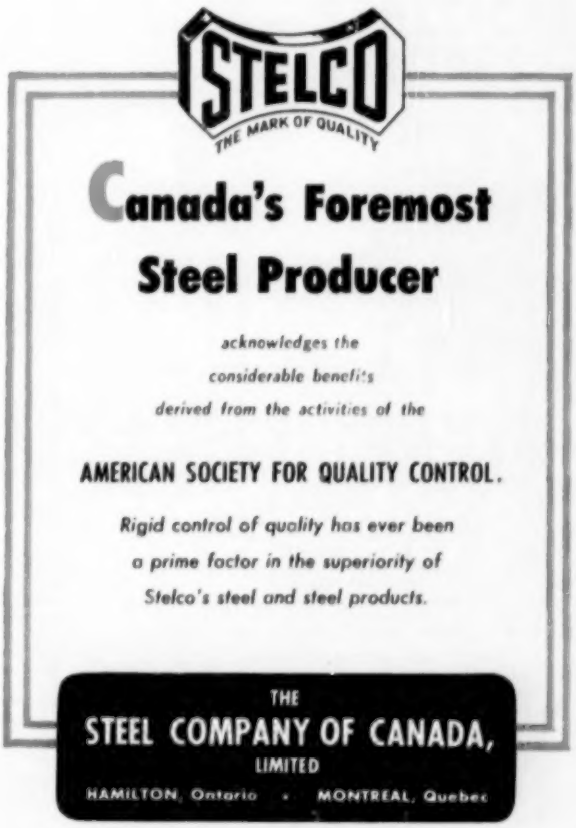
"AS YE SOW . . ."

BIRMINGHAM The Birmingham Section will hold its First Annual Quality Control Forum on Oct. 13 in collaboration with the University of Alabama. The Huntsville Section will be invited to co-sponsor this event.

MICHIGAN The University of Michigan Summer Session and Extension Service in cooperation with the Michigan Section announces a special program of Quality Control by Statistical Methods. This will be a full time intensive program held at the University in Ann Arbor, Mich. The course will be held from Aug. 17-27.

This course has been offered annually since 1948 and has met great success. The enrollment is limited to 60 persons. It is designed for quality control executives and supervisors, inspection chiefs and supervisors, engineers, and purchasing agents. The course is tailored to avoid mathematical technicalities, but will give those who take it the competance to apply statistical control methods successfully in their companies.

Three prominent members of the Michigan Section will be guest speakers at the course. They will be



REGIONAL MEETING AND CONFERENCE SCHEDULE 1955-1956

DATE	CONFERENCE OR MEETING	PLACE	FOR FURTHER INFORMATION CONTACT
September 10	Rutgers Conference	Rutgers University	Dr. Ellis R. Ott, Rutgers, New Brunswick, N. J.
24	St. Louis Conference	Jefferson Hotel, St. Louis, Missouri	Kort K. Flake, Carter Carburetor Corp., St. Louis, Missouri
November 1	Cleveland Second Annual	Cleveland, Ohio	Howard O. Schmidt, Alum. Co. of America, 2210 Harvard Avenue
3-5	Ninth New England	Hotel Statler, Hartford, Connecticut	G. H. Selig, Pratt & Whitney, W. Hartford, Connecticut
17-18	Tenth Midwest	Schroeder Hotel, Milwaukee, Wisconsin	L. S. Eichelberger, A. O. Smith Corporation, Milwaukee 1, Wisconsin
December 9	Princeton	Princeton University	
10	6th Textile Conference	Clemson, North Carolina	
1956 February 9			
10-11	Mid-Atlantic & Aircraft Div.	Washington, D. C.	
21	Rochester Clinic	Chamber of Commerce Bldg., Rochester, New York	Hubert C. Minard, Rochester Society for Q. C., 12 Mortimer St., Rochester 4, New York
March 17-18	4th Annual Pacific N. W.	University of Washington, Seattle, Washington	Charles R. Shaeffer, 1327 South 13th St., Mt. Vernon, Washington
August 20-21	Western Region Conference	Los Angeles, California	E. Cartotto, L. A. Section, 1351 Idlewood Road, Glendale 2, California
October	11th Midwest Conference	Minneapolis, Minnesota	Gayle W. McElrath, University of Minnesota, Minneapolis 14, Minnesota

Deland H. Davis, Leo Harington, and Charles W. Quillen. These men are all from Michigan industry and will present the practical applications of statistics in industry to supplement the teaching staff for the course.

Further inquiries should be addressed to: Dr. C. C. Craig, 106 Rackham Bldg., University of Michigan, Ann Arbor, Mich.

SAN FRANCISCO BAY AREA The Second Annual San Francisco Bay Area Quality Control Conference will be held at Stanford University on Sept. 16. This will be a one day affair jointly sponsored by the Committee on Industrial Engineering of Stanford and the San Francisco Bay Area Section. Keynote speaker will be Brig. General W. P. Farnsworth, Staff Director for Inspection & Quality Control, Office of the Asst. Sect. of Defense, Washington, D. C. Several other speakers of national prominence will be included on the program which will be divided between management sessions and discussions on applied techniques. For reservations contact Professor Grant Ireson, Stanford University, Calif.

ST. LOUIS A one day Managing for Quality Conference is set for Sept. 24 at the Jefferson Hotel in St. Louis. The Panels will cover such interesting items as Plant Wide Quality Control, Quality Control in Management, and many others with all talks being by specialists in their individual fields.

WESTERN MASSACHUSETTS The advanced course in Statistical Quality Control to be held in conjunction with the University of Massachusetts Extension for which college credit is to be allowed will start in late September. The date has not been firmed; however, it is known that the course will go for fourteen weeks and the textbook will be Dixon & Massey's "Introduction to Statistical Analysis." There will be plenty of advance notice as to the start of this course with detailed instructions.

CARNEGIE INST. OF TECHNOLOGY During the coming academic year Carnegie Institute of Technology will offer, in its evening program, two-semester credit courses in Experimental Design, Probability and Mathematical Statistics, and Statistical Quality Control. The courses will meet one evening per week, Monday, Wednesday, and Friday evenings respectively, 7:30-10:30 pm, September, 1955 through May, 1956. Registration for the courses will be Sept. 13, 14 from 6:30-9:30 pm. For further information regarding these courses and regarding graduate and undergraduate day courses, write to Professor Edwin G. Olds, Department of Mathematics, Carnegie Institute of Technology, Pittsburgh 13, Pa.

SOCIETY FOR INDUSTRIAL AND APPLIED MATHEMATICS The Society for Industrial and Applied Mathematics will hold its Second General Meeting at the University of Michigan, Ann Arbor, Mich. on Aug. 30-31, 1955.

ST. LOUIS CONFERENCE
SEPTEMBER 24

The reverse side of the 1955-56 membership card inadvertently carried February 24 as the date of the St. Louis Conference. The correct date of the conference is Sept. 24.

The following is the program of invited talks: "Mathematical Logistic Problems," Dr. Max A. Woodbury; "Practical Methods for Solving Dual Integral Equations," Mr. Francis P. Callahan; "Characterization of Non-Linear Systems," Dr. Lofti Zadeh; "The Effect of Psychological Attitudes on the Outcomes of Games," Dr. Gerald L. Thompson; untitled talk on "mathematical programming," Dr. Richard Bellman; "Some Mathematical Advances in Statistical Physics," Prof. T. H. Berlin; "Remarks on the Tau-Method for the solution of Linear Differential Equations with Rational Coefficients," Mr. Yudell L. Luke.

Other Societies which have scheduled meetings at the University of Michigan during the week of Aug. 29th are: American Mathematical Society; Association for Symbolic Logic; Econometric Society; Institute for Mathematical Statistics; Mathematical Association of America; and Pi Mu Epsilon Fraternity.

OPERATIONS RESEARCH SOCIETY OF AMERICA The Seventh National Meeting of the Operations Research Society of America will be held on Aug. 15-17 at the Hotel Statler in Los Angeles, Calif. Mr. Robert A. Bailey, Military Operations Research Division, Lockheed Aircraft Corp., Burbank, Calif. is the meeting chairman.

"FOR MANY ARE CALLED, BUT FEW ARE . . ."

MICHIGAN At the last meeting of the section, the newly elected officers for the 1955-56 season were announced. They are as follows: Chairman, Dr. W. D. Baten, Michigan State University; Vice Chairman, Dr. E. C. Yehle, University of Michigan; Secretary, Stephen J. Adams; and Treasurer, Thomas J. Anderson.

SAN BERNARDINO San Bernardino Section recently held installation ceremonies for their newly elected officers for the 1955-56 year. The following officers were inducted: Chairman, Jordan A. Engberg, Norton AFB, San Bernardino; Vice Chairman, Harold Batchelor, General Electric Co., Ontario; Secretary, James A. Butcher, Convair Corp., Pomona; and Treasurer, Irwin A. Spitzer, Kaiser Steel Corp., Fontana.

SALT LAKE CITY The following officers have been elected for the 1955-56 season: Chairman, Wm. A. Hoagland; Vice Chairman, Osmund Harline; Secretary, Leon K. Nelson; and Treasurer, Sydney H. Drummond.

TENNESSEE The following people were elected officers of the Tennessee Section for 1955-56: Chairman, Mr. R. L. Murray, Hardwick Mills, Inc., Cleveland; Vice Chairman, Prof. R. M. LaForge, Dept. of Industrial Engineering, University of Tennessee, Knoxville; Secretary, Mr. R. E. Rinella, Proctor and Gamble Defense Corp., Milan; and Treasurer, Dr. M. T. Giachino, Grace Chemical Co., Memphis.

TORONTO The following are the Executive Officers elected for 1955-56: Chairman, R. Cardno, Canadian General Electric Co., Toronto; Vice Chairman, D. A. Irwin, Canadian Arsenals Ltd., Scarbora; Secretary, B. G. Graham, Canadian Arsenals Ltd., Long Branch; and Treasurer, M. J. O'Callaghan, De Haviland Aircraft of Canada Ltd., Toronto.

UTICA The four newly elected officers for the fiscal year are: Chairman, Mr. George V. Wood, Revere Copper & Brass Inc., Rome; Vice Chairman, Mr. Paul F. Russo, Bendix Aviation Corp., Rome; Secretary, Mr. Joseph F. Drozd, General Electric, Utica; and Treasurer, Mr. A. C. Cirillo, Chicago Pneumatic Co., Utica.

WESTERN MASSACHUSETTS The four elected officers for this section for the 1955-56 season are as follows: Chairman, John Hinchen, Monsanto Chemical Co., Springfield; Vice Chairman, Joseph Griffin, Westinghouse Electric Co., Springfield; Treasurer, George Rice, Old Colony Envelope Co., Westfield; and Secretary, Carl Bauman, Monsanto Chemical Co., Springfield.

WINDSOR The following tried and true have been elected to office for the year 1955-56 by an unanimous vote: Chairman, M. F. Kennedy; Vice Chairman, G. A. Dowling; Secretary, C. E. Laforet; and Treasurer, James McMillan.

WORCESTER The following is the listing of officers for Worcester Section for the year 1955-56: Chairman, Arthur P. Pingalore, General Electric Co., Ashland; Vice Chairman, Warren Arnold, Jr., Draper Corp., Hopedale; Secretary, P. Roy Leaman, Bay State Abrasive Products Co., Westboro; and Treasurer, Francis Olson, Norton Co., Worcester.

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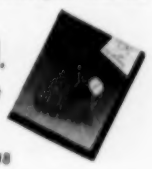

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DIVISIONS

Administrative Applications Division

The organization meeting was held in the Dallas Room of the Hotel Statler in New York on May 24. Approximately 75 of the more than 250 members were present. Howard L. Jones was elected Chairman; Dale L. Lobsinger, Vice Chairman; William F. Buhl, Secretary; and Harmon S. Bayer, Treasurer. Committee Chairmen are Dr. Carl Noble, Program; Dr. William R. Pabst, Jr., Publications; William F. Buhl, Bylaws; Prof. Grant I. Butterbaugh, Education and Training; Dr. Alex L. Hart, Relations with Other Technical Societies; Dale L. Lobsinger, Nominations; Harmon S. Bayer, Membership; Vida Grace Hildyard, Publicity and Promotion. Additional committees being formed are Clerical and Accounting Applications, Industrial Engineering Applications and Management Applications.

Chemical Division

Two meetings were held by the past and new Officers and Councilors, one meeting in Chicago before the Convention, and the second meeting during the Convention. These meetings concentrated on ways and means of improving service to the members, also providing continuity of Division activities. They also helped to clarify our goals and objectives for the coming year. Among the objectives will be a strengthening of Chemical Division programming to the end that the Chemical Division will promote a speaker from the Chemical Industry at every regional and local conference, as well as to as many local meetings as possible. Much of the demand for such speakers must of necessity come from the local sections and from Conference Committees.

Another aim of the Chemical Division will be the strengthening of Councilors' duties and responsibilities. These have already been outlined and further work is continuing on more explicit definition of the relationship between the Divisional Councilors and the National Society. One of these responsibilities is to serve as a direct contact between the Chemical Division and the sections included in the councilor's district. We urge that all members of the local sections and local committees avail themselves of the facilities of the Chemical Division by directing their requests to the Chemical Division by way of the District Councilor. The names of the Councilors were previously published in the July issue. These Councilors will handle all requests promptly, or if needed, will transmit them directly to the Chemical Division for further consideration.

MEMBERSHIP CORNER

Detailed planning, like that of many progressive industrial organizations is a requisite to obtain maximum results for any project. Some of the activities of the Southern Connecticut Section, which we believe are of major importance in attracting and holding membership may be of interest to other sections.

1. Careful follow-up of National dues bills and the renewals progress, with personal contact as a must.
2. General letters to the membership over the Membership Chairman's signature encouraging members to invite interested associates to meetings.
3. Distribution of membership lists showing company affiliation and position as a means of promoting better acquaintance and knowledge of those who comprise the membership.
4. Assignment of Executive Committee members to greet those attending meetings. Introductions are very helpful to get newcomers acquainted, creates good will and promotes fellowship. People need to enjoy coming to meetings.
5. We maintained a 300 name non-member mailing list, with a careful and periodic review to keep it effective.
6. Pocket cards were distributed at each meeting and contained a brief message of welcome, a description of the Section and Society activities and an invitation to join. Cards were collected, attendance by companies and area tallied and membership committee followed up non-members who attended more than once.
7. Section requirements as to meeting programs were studied and speakers and subjects were selected having maximum appeal for the membership. The program material was geared to serve section members and is one of the most important factors in attracting new members and insuring renewals.
8. Extra copies of the year's wallet size program with a synopsis of speaker's topic, general information about the Society and Section were mailed to non-members and also distributed at the first several monthly meetings.
9. An Education Program (particularly basic or introductory) will attract many non-members. A well conducted course, aimed at serving the indicated needs of the group, will automatically lay the ground work for acquiring new members. Names were placed on a non-member list for inclusion in our mailings. Class sessions were scheduled for the same week day as the regular monthly membership meeting and as each date conflicted, the class session was deferred to the following week and all were invited to attend the meeting.
10. A Section Development Program was initiated to attract new members from industries not represented so as to broaden the membership base as well as increase it numerically. It consisted of a four-page cartoon brochure, a copy of our yearly program, a personalized covering letter and a membership application; and was mailed to a selected list of non-members having quality responsibilities in area industries. The letter was followed up by personal telephone calls if there was no response to the invitation to personally contact the sender. A sample of this cartoon folder is available from the Southern Connecticut Section.

The Southern Connecticut Section hopes that this may provide ideas which have not already been used to increase section stature and thus attract a broader membership.

SIGNIFICANT DIFFERENCES

Arthur P. Woods, Jr., Armco Steel Corporation, was presented the AISI Medal at the Annual Meeting of the American Iron and Steel Institute, May 25-26, 1955.

Mr. Woods won the award for his paper entitled "Statistical Methods Applied to Steel Plant Operations," which was presented at the Eighth Annual ASQC Con-

vention in St. Louis. It was selected for presentation at the Annual Meeting of AISI, May 25-26, 1954, and by special permission was actually presented at this meeting before it was presented at the ASQC convention, for which it was specifically prepared.

The Dow Chemical Company has announced the appointment of Harry L. Wehrly as Quality Control Manager of its Midland Division. Included among his duties will be the coordination of quality control activities connected with the manufacture of goods produced at the Midland plant. Wehrly is well known in Quality Control circles and is currently serving as chairman of the Chemical Division of ASQC.

Robert K. Mueller, Plastics Div., Monsanto Chemical Company, was elected as one of the four divisional vice presidents of the American Management Association in an announcement recently made by the Association's president, Lawrence A. Appley.

Wyatt H. Lewis has been promoted from Manager of Quality Control at the Ontario Plant of General Electric to Quality Control Engineer of General Electric's Manufacturing Services Division in Schenectady, N. Y. Mr. Lewis is a founding member of ASQC and a Fellow of the Society. Richard J. Zerveck has been named to the post of Manager of Quality Control at Ontario, replacing Mr. Lewis.

Bibliography

JOSEPH MOVSHIN, *Editor*

Assisted by the Editorial Committee, St. Louis Section, ASQC

On matters concerning the Bibliography Department, send correspondence, suggestions, and contributions to:

Joseph Movshin
9220 Old Bonhomme Road
St. Louis 24, Mo.

APPLICATION—
CHEMICAL INDUSTRY

STATISTICS SLASH REJECTS
(Chemical Week—v. 75, n. 25, Dec. 18, 1954, p. 80)

This article very briefly discusses the savings made by the application of statistical quality control in Dupont's Kinetic Chemical Division.

APPLICATION—
PETROLEUM INDUSTRY

STATISTICS FOR EVERYDAY USE, by C. T. Shewell (Humble Oil & Refining Co., Baytown, Texas)
(Petroleum Processing—v. 9, n. 4, Apr. 1954, p. 524)

This article is the first in the series describing nine statistical techniques and their applications in the petroleum processing industry. Three techniques are discussed in this first article of the series. These are measures of central tendency, measures of dispersion, and the question of discarding bad data. The basic frequency distribution is presented. Examples of problems are given. A table is provided whereby the probability of individual extremes belonging to the given population may be estimated.

STATISTICAL QUALITY CONTROL, by John F. Walter (University of Pittsburgh, Pittsburgh Pa.)
(Petroleum Refiner—v. 33, n. 2, Feb. 1954, p. 149)

Statistical Quality Control is presented as a tool which may be applied to a fractionating tower to reduce quality product variability. The fact that fewer process adjustments are necessary when the process is in control is stressed. Figures showing control charts for average and range and moving ranges are shown.

ANALYSIS OF VARIANCE

STATISTICAL EXPERIMENT IN PLASTIC FABRICATION, by Edwin C. Harrington (Manager of Industrial Statistics. Monsanto Chemical Company)
(Society of Plastic Engineers, Journal—v. 11, n. 6, June 1955, p. 19)

Discusses 2 x 2 factorial type of statistical experiments and interpretation of variants. Analysis of a typical case is followed through to illustrate the techniques employed. Torque strength of molded pieces is used as the example.

For other articles in this series see the July 1955 Bibliography.

MANAGEMENT & PERSONNEL, GENERAL

WHO SHOULD BE RESPONSIBLE FOR QUALITY CONTROL? by Kenneth M. Smith (Foundry Consultant)
(Foundry—v. 83, n. 7, July 1955, p. 125)

While the application of statistical methods have developed Quality Control to essentially a scientific status, know-how in itself does not guarantee an effective quality control program. The establishment of responsibility for the many aspects of quality control throughout the organization are an important element in the overall program. The author discusses the relative areas of activity of management, technical and operating levels in general terms and discusses how responsibility may be divided between the area of "Know-how", "Know-when and where" and "Know why".

"Know-why" is top management. The area of "Know-how" is a technical group and the area of "Know-when and where" is the application of statistical and other techniques in the operating departments. This article discusses this problem in general terms of the foundry operation.

PINNING DOWN QUALITY RESPONSIBILITY, by Norbert Lloyd Enrick
(Modern Textiles Magazine—v. 36, n. 6, June 1955, p. 50)

This article, the fifth in the series, stresses the importance of establishing primary responsibility for quality and of following through to see that this responsibility is met. Special forms are shown to clearly define authority and responsibility and for follow up to measure quality. Centralized surveillance to continuously watch

overall quality performance is used. A quality bonus system for operators in the textile industry is also discussed.

INDUSTRIAL MANAGEMENT

ENGINEERING ECONOMY AND OPERATIONS RESEARCH, by L. G. Mitten (Assistant Professor of Industrial Engineering, The Ohio State University)
(Journal of Engineering Education —v. 45, n. 7, Mar. 1955, p. 560)

This article discusses the relationship between engineering economy and operations research. These are compared on the basis of purpose, methodology, and techniques. It is the writers opinion that the techniques of operations research may become important tools of engineering economy. In developing this idea, the author discusses the idea of model construction and criteria measurement.

A STATISTICAL MODEL FOR TIME STUDY, by H. P. Edmundson and R. T. Nelson
(The Journal of Industrial Engineering—v. VI, n. 3, May-June 1955, p. 6)

This article proposes the use of a statistical model as the basis for time study evaluation techniques. This is based on the ideal that the speed-rating factor and the actual performance time are to be considered random variables, dependent upon chance occurrence at the moment of observation. The three factors, or parameters, influencing the study are the operator, the observer, and the actual time for a given operation. A probability distribution is developed using these factors. The observed times are determined from what amounts to a scatter diagram and line of regression of the data by a sample technique described.

MATHEMATICAL PROGRAMMING AS AN AID TO DECISION MAKING, by Gifford H. Symonds (Chairman, Operations Research Sub-group Esso Standard Oil Company, Linden, New Jersey)
(Advanced Management—v. XX, n. 5, May 1955, p. 11)

The author describes in detail the mathematical models used in several operations research approaches are graphically illustrated in a series of charts presenting the relationship of variables in various types of problems. The material is presented in terms of a "scientific method" approach to several typical problems.

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MISCELLANEOUS

TESTING AND INSPECTION 1855-1955
(The Iron Age—v. 175, n. 27, June 1955, p. K-2)

This issue of *The Iron Age* has as its theme "100 Years of Metalworking." Section K reviews the past development of testing and inspection equipment and methods in the metal working industry and continues with the description of modern technical equipment. The future is then briefly discussed in two major aspects, the use of automatic inspection equipment and quality control.

STATISTICS

ESTIMATION OF THE PARAMETERS OF A SKEWED DISTRIBUTION BY LINEAR SYSTEMATIC STATISTICS, by A. E. Sarhan
(Journ. Am. Stat. Assoc.—v. 50, n. 269, Mar. 1955)

TABLES OF PERCENTAGE POINTS FOR THE STUDENTIZED MAXIMUM ABSOLUTE DEVIATE IN NORMAL SAMPLES, by Max Halperin, Samuel W. Greenhouse, Jerome Cornfield, and Julia Zalokar
(Journ. Am. Stat. Assoc.—v. 50, n. 269, Mar. 1955, p. 185)

MISCLASSIFICATION IN 2 x 2 TABLES, by I. Bross
(Biometrics—v. 10, Dec. 1954, p. 478)

A 2 x 2 FACTORIAL WITH PAIRED COMPARISONS, by R. M. Apelson and R. A. Bradley
(Biometrics—v. 10, Dec. 1954, p. 487)

SIMPLE SEQUENTIAL PROCEDURE FOR TESTING STATISTICAL HYPOTHESES, by C. K. Tsao (Annals of Math. Stat.—v. 25, Dec. 1954, p. 687)

ERRATA

Following publication of the "Clarification and Further Comments on the 'Use of the Range in Comparing Variabilities'" by Acheson J. Duncan (IQC, May 1955, p. 70) the following errors were discovered:

1. Column 2, line 12
   $s^2 = \Sigma (X - \bar{X})^2/k(n-1)$
   should be
   $s^2 = \Sigma (X - \bar{X})^2/(kn-1)$
2. Column 3, line 20
   $s^2 = \Sigma (X - \bar{X})^2/k(n-1)$
   should be
   $s^2 = \Sigma (X - \bar{X})^2/(kn-1)$
3. In the footnote at the end, the left-hand term of the N_R, should be $N_{\bar{R}}$.

MEAN AND COEFFICIENT OF VARIATION OF RANGE IN SMALL SAMPLES FROM NON-NORMAL POPULATIONS, by D. R. Cox
(Biometrika—v. 41, Dec. 1954, p. 469)
DISTRIBUTION OF THE RATIO, IN A SINGLE NORMAL SAMPLE, OF RANGE TO STANDARD DEVIATION, by H. A. David, H. O. Hartley, and E. S. Pearson
(Biometrika—v. 41, Dec. 1954, p. 482)
DISTRIBUTION OF RANGE IN CERTAIN NON-NORMAL POPULATIONS, by H. A. David
(Biometrika—v. 41, Dec. 1954, p. 463)

OPERATIONS RESEARCH

QUEUEING THEORY, by William T. Morris (Instructor, Department of Industrial Engineering, Ohio State University)
(The Journal of Industrial Engineering—v. VI, n. 3, May-June 1955, p. 26)

This article describes the mathematics involved in the probability of the queueing theory and develops operating equations for the use of this technique.

What's New?

ROY A. WYLIE, *Editor*

News releases describing new products and literature should be sent to:
George R. Foster, Mng. Ed.
Room 6123 Plankinton Bldg.
161 W. Wisconsin Ave.
Milwaukee 3, Wis.

When inquiring about "What's New?" items, please mention INDUSTRIAL QUALITY CONTROL.

The Cornell-Dubilier Electric Corp., South Plainfield, N. J., announce their new deluxe Model BF-70 Capacitance-Resistance Analyzer for industrial testing purposes. This ten pound portable instrument, quickly and accurately measures the important characteristics of essentially all types of capacitors and resistors. The principal feature is a direct reading calibration scale to provide simplified measurements without the use of mutipliers or charts. The Model BF-70 locates capacitor opens, shorts and intermittents; high and low capacities; and detects high leakage and high power-factor in electrolytic capacitors, as well as low insulation resistance in paper, mica and ceramic dielectric capacitors. It is also possible to make sensitive Capacitance measurements between wires and shieldings; transformer windings, cable wire and other similar conditions. The built-in panel meter is arranged for independent external voltage measurements to 750 volts and current measurements to 75 milliamperes. The net price of this instrument is $71.50. Bulletin BF-70 available from the manufacturer describes the instrument in detail.

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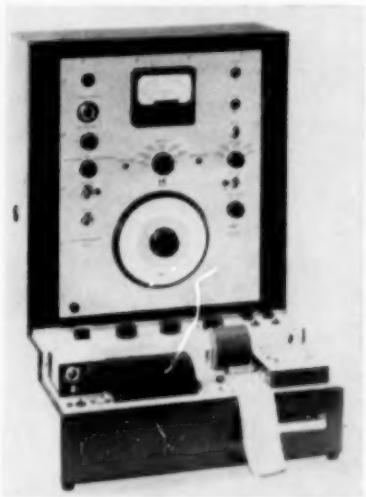

Sound measurement and analysis has been simplified by the recently developed Third Octave Spectrum Analyzer Model BL-2109, distributed in the U.S.A. and Canada by the **Brush Electronics Company**, 3405 Perkins Avenue, Cleveland 14, Ohio. This instrument provides physical measurement data that is easily correlated to subjective tests for loudness of sound or the intensity of vibration through the use of a narrow frequency band analysis. The Third Octave Spectrum Analyzer works in the range of frequencies from 35 to 18,000 cycles per second. Through the use of 27 fixed one-third octave band filters with the associated low-noise, high-gain amplifiers, the instrument affords either manual or automatic switching, with the analysis data being read from a meter or graphically recorded through a connection to the Level Recorder, Model BL-2304. Also available is a console combination of the Third Octave Spectrum Analyzer and the Level Recorder. The combination is designated Model BL-2311 Third Octave Spectrum Recorder. The combination permits the automatic third octave analysis and simultaneous recording of the information on a frequency preprinted chart. The chart gives a complete analysis of amplitude versus each one-third octave band of frequencies with an overall level shown at the end of the filter scanning. The automatic feature makes possible a continuous monitoring of noise levels with the analysis being recorded, thus eliminating the necessity for personnel being in attendance.

★ ★ ★

George Scherr Optical Tools Inc., 200 Lafayette Street, New York 12, N. Y., have just announced that they can now offer a complete line of Toolmakers Microscopes starting from a small instrument with a 1.5 x 2 inch range up to the largest available anywhere (8 x 40 inch range). The new addition to the line is the Scherr Toolmakers Microscope, a completely universal, yet economically priced instrument. The new Toolmakers Microscope permits measuring of co-ordinates to 0.0001 inch, angles to one minute of arc, in addition to radii, concentric circles, screw threads, etc. For economy in

production, the stand itself is manufactured in New York, the optics being furnished by the optical firm of E. Leitz, Inc., Wetzlar (Western Zone) Germany. The measuring stage has a range of 1.5 x 2 inches with 1 inch micrometer drums reading in 0.0001 inches. Additional movement in both directions is obtained by the use of Gage Blocks. An unusual feature of this instrument is the ability to interchange oculars very quickly and a variety of ocular heads are available for angular measurements to one minute of arc; concentric circles; and screw threads in addition to standard hairline cross oculars.

* * *

"On the spot" balancing can be accomplished by anyone with the new Portable Balancer recently developed by the **Tinius Olsen Testing Machine Company**, 348 Easton Road, Willow Grove, Pa. The self contained unit provides a means for balancing any part which may not be handled economically in a precision type balancing machine. It is especially useful for large parts and provides a tool so that a complete vibration analysis as well as dynamic balancing can be done easily yet accurately. The machine is capable of balancing parts at speeds of 250 RPM. The angular location and the amount of correction weight required in two selected correction planes are determined without guesswork. The entire unit is housed in a light weight carrying case and consists of one inertia type pickup, a stroboscope light, an amplifier with range switch and all necessary cables. Additional information is available from the manufacturer.

* * *

Size Control Company, Division of American Gage and Machine Company, will display new low cost mater ring gages made within ±0.0002 inches of any specified size—at Booth 417, Machine Tool Show in Chicago Sept. 6-17. The Boremaster gage is used for gaging and setting indicating bore gages and inside micrometers. The exact size is shown on the master to four decimal places and the ring is accurate to 0.0001 inches in roundness, straightness, and taper, non-accumulative. Rings are available from 0.1870 to 3.000 inches and larger sizes are available in AGD tolerances. Boremaster rings are made from tool steel which has been hardened and stabilized. The finish is honed 4 to 6 microinches and prices range from $7.90 in 0.187—0.240 inches up to $35.40 in 2.510—3.000 inches. Complete details are furnished in a 4-page "Boremaster" bulletin available from the manufacturer at 2500 W. Washington Blvd., Chicago 12. Ill.

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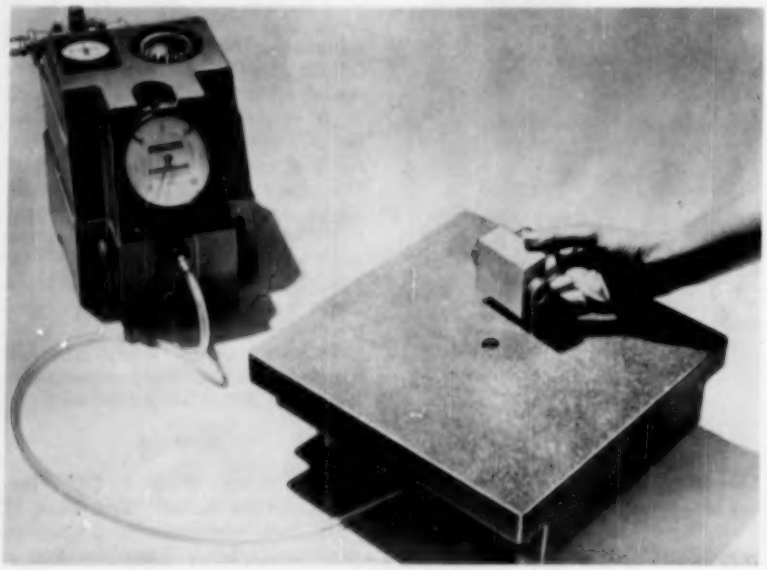


Federal Products Corporation, 1144 Eddy Street, Providence 1, R. I., is now manufacturing a new gage for checking surface flatness. This gage, designed as Model A-582 B-4, has two essential parts. One is a Federal Dimensionair Air Gage, equipped with a universal Air Gaging spindle known as the AirProbe. The second part is a Rahn, Black Granite Surface Plate. The standard plate is 12 x 12 x 3 inches with a guaranteed accuracy of 0.000050 inches for any 2 x 2 foot area. Plates of other sizes or accuracies will be furnished on request. The AirProbe is set into the center of the surface plate so that the contact point extends slightly above the surface. A three-foot plastic hose connects the AirProbe with the Dimensionair so that the dial may be positioned in a convenient location. In checking flatness a part is placed on the surface plate and moved across the contact point. Any variation in the surface will depress the spindle a different amount and the difference can be read on the Dimensionair Dial in increments of 0.000050 or 0.000020 inches, depending on which model Dimensionair is used. AirProbes can be supplied in ranges of 0.003, 0.006, 0.015 and 0.030 inches to suit various tolerance ranges. The addition of longer contact points to the AirProbes enables the gage to be used as a height or depth gage.

* * *

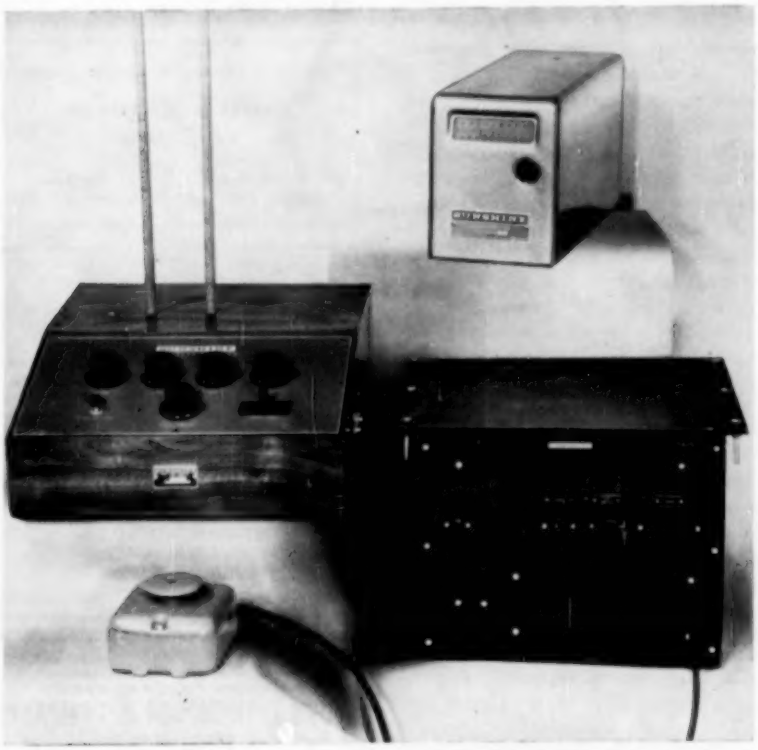
Technology Instrument Corporation of Acton, Mass. announces the Type 800-A Vacuum Voltmeter for extended-range voltage, resistance, and current measurement. The instrument combines the inherent accuracy of the basic voltmeter with a highly degenerative amplifier circuit. Combined with the further improvement of developing the feedback voltage across a single precision resistor, the degenerative network provides previously unachieved stability. The circuitry of the 800-A provides this long-term stability by elimination of the tube-aging problem and the effect of fluctuations of the meter's copper-wound coil resistance due to temperature and manufacturing variations. The instrument is designed for rugged field duty as well as precision laboratory work. AC voltages may be read over the frequency range from 15 cps to 100 mc on eight full scale ranges of 0.1 to 300 volts; nine DC voltage scales from 0.1 to 1000 volts; resistances on a single scale calibrated from 0.2

to 500 ohms with nine multipliers from X0.1 (0.02 to 50 ohms) up to X10 meg. (2 to 5000 megohms); and nine direct-current, full-scale ranges from 0.001 microampere to 100 milliamperes. Input impedance for DC volts is 100 megohms; for AC volts, probe input capacitance is 5uuf. and 10 megohms (nominal) at lower frequencies; for direct current, input impedance is such that input voltage drop is 0.1 volt at full scale on all ranges. Size of the unit is 7 x 7 x 9 inches and weight is 11¾ lbs.

★ ★ ★

Unit Process Assemblies, Inc., 75 East 4th Street, New York, N. Y., has announced a non-destructive thickness tester for the metal finishing industry. The unit will test thickness of metals deposited on metals, metals on non-conductors, and non-conductors on metals. It will accurately give direct readings of thickness of virtually any coating on any base, including silver on brass, copper on die-castings, nickel on brass, metallizing on plastics, or metallic coatings on ceramics. The electronic unit is compact and portable, permitting use in almost any location. Thicknesses are read directly from the instrument, and are determined in a matter of seconds.

★ ★ ★



Sunshine Scientific Instrument Company, 1810 Grant Avenue, Philadelphia 15, Pa., announces a high-accuracy, non-destructive coil turn counter. The coil turn counter quickly measures the number of turns on coils wound on non-magnetic forms with an accuracy of 0.1 percent. It is available in three models with ranges 0-11,110; 0-31,-110; and 0-61,110 turns. The coil to be tested is placed over a test rod and its turn count compared with a standard coil mounted within the equipment. The instrument operates from a 115 volt 60 cycle source and reads directly in number of turns. A wide range of coil sizes may be tested. Catalog No. 16 describing this instrument in detail is available from the manufacturer.

★ ★ ★

A portable, laboratory model Turba-Film Evaporator for pilot plant and quality control study of the unit operations of evaporation, single step distillation, deordorization, heating, cooling, or other heat treatment is now available from **Rodney Hunt Machine Company,** Orange, Mass. The evaporator is built of type 316 stainless steel throughout and is designed for the use of heating mediums up to 250 psig and 700° F. The heat transfer area is one square foot. The condenser is a vapor-in-tube unit of 316 stainless steel in contact with process vapor. The surface condenser provides for handling the maximum amount of vapor which can be generated from the evaporator, at cooling water temperature of 60° F. Auxiliary facilities can be provided for supplying water at 34° F. to the condenser. A variable speed drive is arranged to permit rotor speed changes as required for technical studies. The Turba-Film Evaporator can be supplied as an individual unit with stand or with auxiliary condensing equipment, or as a complete packaged plant including vacuum equipment, feed pumps, discharge pumps, and instruments as required. The evaporator concentrates, distills, deodorizes, degasses, deaerates, heats, cools or otherwise processes liquids, gases, and sluries in a few seconds by continuous operation. The evaporator is capable of removing as much as 5,000 pounds of water per hour. It is designed to handle organic and inorganic chemicals, solvents, latices, pharmaceutical "mycins", vitamins, juice concentrates, edible oils, gelatine, glues, confectionaries, coffee and detergents.

★ ★ ★

New Literature

An 8-page illustrated bulletin on applications of master balls in tool room and production gaging is announced by Industrial Tectonics, Inc., 3684 Jackson Road, Ann Arbor, Mich. Topics covered include checking depth of drilled holes; checking angle and diameter of internal tapers and locating the apex of the cone; measuring the diameter of cylindrical holes using two and four balls, and more than 50 equations are given for these and related applications together with explanatory drawings and examples.

Petz-Emery Inc. has released a four-page bulletin No. 455 on its "Em-re" Dial Indicators. The indicators are fully jeweled, completely shock-proof, anti-magnetic, have instrument gearing, no-glare bezel, and are of simple construction and light-weight. The complete line of 24 models is built around 31 parts. All but six parts are common to all models. The bulletin is available from the manufacturer at Pleasant Valley, N. Y.

(Continued from page 1)

As a member of the quality control staff could you help the inspection department select a gage from company x, y, or z? You should be able to because this is a decision to be made and SQC is a decision tool. Could you assist the design engineer in selecting a particular type and supplier of material for a new part he is working on? You should be able to convince him that your assistance would help. This is a decision to be reached. If your tooling or production department were getting ready to buy a new mill or profiler or bottling machine or what have you, would you be ready to offer advice on the selection of the particular one? No? Why not? SQC is a sharp decision tool and this is a very important decision to be reached. A poor machine could cost your company many thousands of dollars each month on scrapped and reworked parts.

Many of you are hard at work, of course, on vendor certification programs of one kind and another, others are being asked to certify the purchase of parts and production equipment after the purchase has already been negotiated. Wouldn't it be much wiser, less expensive, and much easier on everyone's nerves if you offered the services of SQC before the fact—at the time the decision is being reached? SQC is a great decision tool and you are the man who knows how to apply it.

—GRF

Metropolitan Section Contributions

The Metropolitan Section recently contributed $50.00 to the Brumbaugh Award Fund and a like amount to the Shewhart Medal Fund. The Executive Secretary acknowledges these contributions and expresses the thanks of the Officers and Directors of the Society.

POSITIONS WANTED

Address all replies to box number references to: American Society for Quality Control Room 563, 50 Church Street, New York 7, N. Y.

FIELD QUALITY REPRESENTATIVE will cover New York, Conn., R. I., and Mass. for mechanical, electrical, and chemical products. Industrial management degree, college Q. C. and statistics. Senior member ASQC, 10 years industrial quality experience. Please reply to Box 12B1 at the above address.

QC ENGINEER desires management position. Age 28; four years experience as supervisor controlling packing equipment by SQC methods. Have also developed and implemented production efficiency methods. B.S. degree, pre-engineering and majored in statistics for QC. Please reply to Box 12B2 at the above address.

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STATISTICIANS WANTED

Progressive and Expanding Chemical Company has openings for Statisticians with interests and experience in the Physical Sciences. Bachelors Degree or equivalent in Chemistry or Engineering, and graduate work in Statistics or experience in experimental design and analysis of physical data. Work affords application of a variety of statistical methods to research, development and production problems, such as design and analysis of experiments and sampling programs, quality control, determination of physical and economic optimum conditions. Excellent opportunity for personal growth and advancement. Please reply to Box 12P1 at the above address.

GLASS CONTAINER MANUFACTURER has an opening for a young man in quality control work. Experience desirable but not essential. Age 25 to 30. Reply in confidence giving background in detail and salary expected. Please reply to Box 12P2 at the above address.

QUALITY CONTROL MEN needed in new Electronic Components Department, should have B. S. degree with experience in electronics or chemical processing using statistical techniques. Located in Finger Lakes region, upstate New York. Forward resume in confidence with salary expectations to Personnel Department, General Electric Company, West Genesee St. Rd., Auburn, N. Y.

QUALITY CONTROL SUPERVISOR—Progressive growing company in desirable western New York location has excellent opening for chemical, mechanical or industrial engineer to organize and head up quality control program. A minimum of five years experience in quality control and inspection desired including working knowledge of statistical quality control. Please reply to Box 12P3 at the above address.

WANTED Q. C. ENGINEER

To supervise quality control inspection in the Hartford, Conn. area for national organization marketing proprietary fastener products. Good opportunity in an expanding organization. Salary open subject to experience and background. Please reply to Box 12P4 at the above address.

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